Caloosahatchee Basin Integrated Surface Water – Ground Water Model

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Project :	Project No.
Caloosahatchee Basin Surface Water – Ground Water Model	50155
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	Approved by:

Version	Description	Author	Control	Approved	Date
1	Final report	TVJ	JTK	JTK	6-25-1999

Key words	Classification :
Caloosahatchee river basin, Florida. Lake Okeechobee discharges, irrigation, water management, water resources assessment, MIKE SHE - integrated hydrological model, surface water - ground water interaction and dynamics	☐ Open ☐ Internal ☒ Belongs to client

Caloosahatchee Basin Integrated Surface Water – Ground Water Model (ISGM)

June 1999

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1 INTRODUCTION

1.1 Caloosahatchee basin

The Caloosahatchee basin is located in central Florida (Figure 1) and covers an area of approximately 1,200 mi^2 (3,100 km2). The freshwater part encompasses the area from Lake Okeechobee upstream to the Franklin lock (S-79) downstream - an area of approximately 1,050 mi^2.

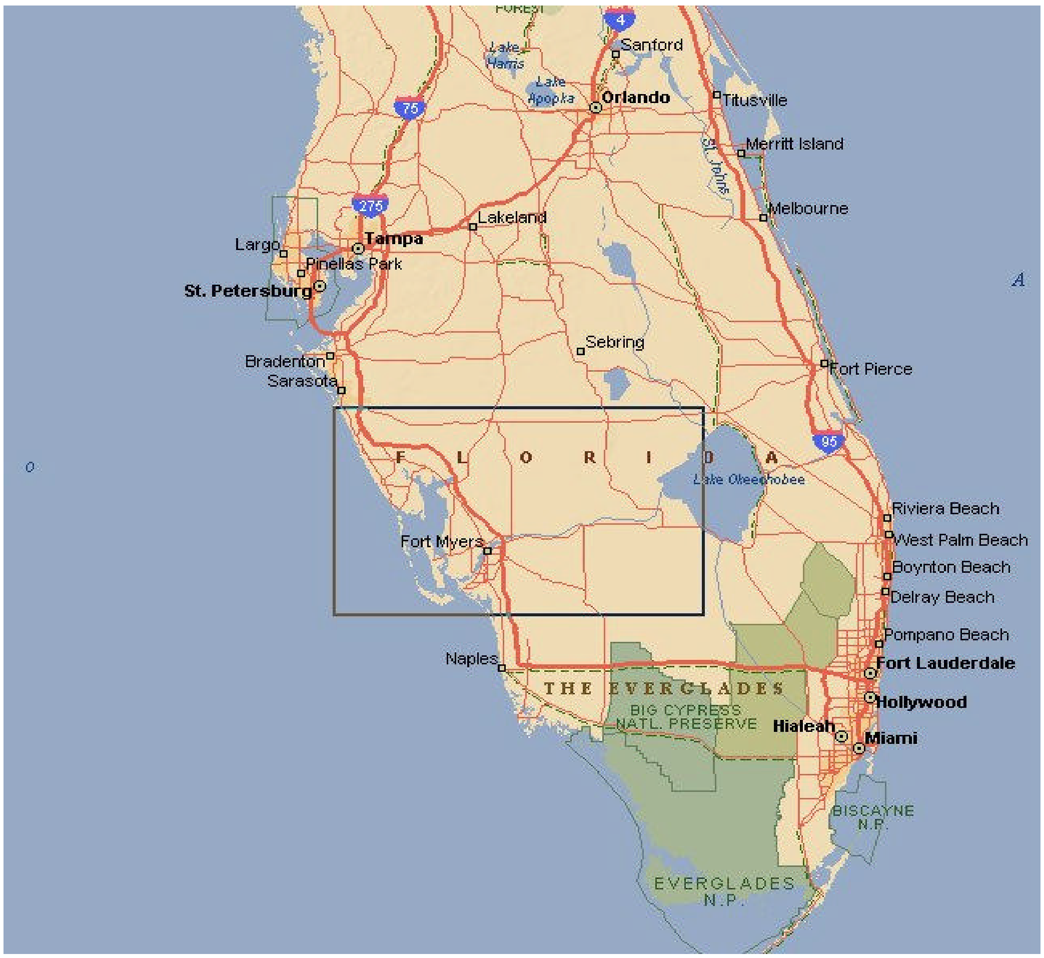

Figure 1 Central and South Florida

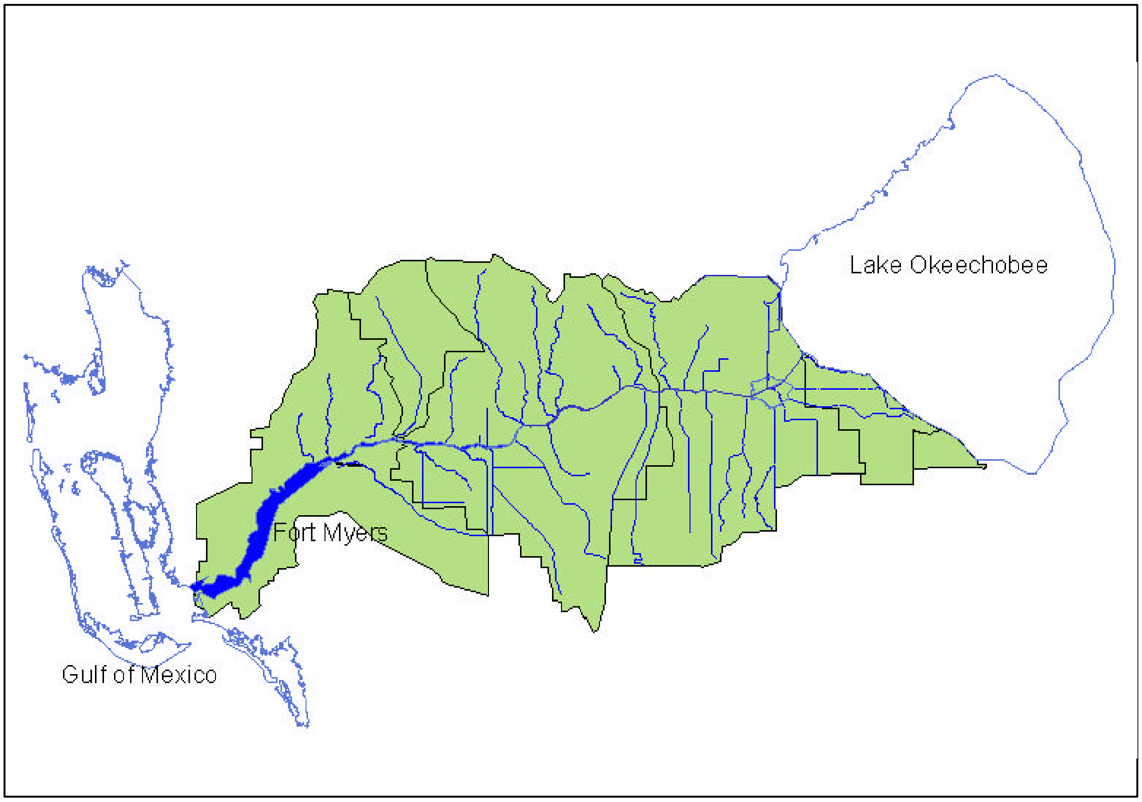

Figure 2 Caloosahatchee basin

The basin is relatively flat with little or no topographical relief. Larger depressions and sloughs with the capacity of retaining large volumes of storm water have been partially drained as part of agricultural development. A large number of wetlands and retention ponds are, however, found scattered across the basin.

The surface water flow is to a large extent controlled by the dense river network The Caloosahatchee river (C-43) receives water from Lake Okeechobee upstream at Moorehaven Lock (S-77). Ortona Lock (S-78) found approximately 16 miles (26 km) downstream drains the eastern part of the basin. The freshwater upper part of the river is separated from the saline lower part and Franklin Lock (S-79) 43 miles (69 km) downstream Lake Okeechobee.

The C-43 canal passes through the depression areas at Lake Hicpochee (5,400-10,500 m). A number of major irrigation and drainage canals are connected to C-43 downstream the lake on the southern side. The water is pumped from C-43 to maintain target water levels in the irrigation canals. Weirs are constructed to increase the water levels in each sub-section of the canals. On the northern side drainage canals and natural streams discharges, mostly unregulated, into the main C-43 canal.

A large number of structures control the flow throughout the basin. On C-43 the locks at S-77, S-78 and S-79 are operated for navigational purposes and for water level control. Further upstream in tributaries a large number of gates, weirs and pumps control flows and water levels. The structures regulate both drainage and irrigation water supply.

The soils are generally coarse and sandy with high infiltration capacity. Horizons of low permeable finer sediments are found locally especially in depression areas.

The upper aquifer system consists of shells, sand and limestone with a relatively high hydraulic conductivity. Shallow water tables are found in most parts of the basin. The water table response to rainfall indicates a close link between rainfall, surface water and groundwater. The Tamiami aquifer in the eastern part and the Sandstone aquifer in the western part of the basin constitute the major sources of groundwater in the basin.

The basin is characterized by a direct coupling between the surface water and groundwater. Effective drainage schemes, high conductivities for the subsurface flow and high hydraulic contact between aquifer and canals causes a rapid runoff to C-43 following rainfall events. Comparison between rainfall records and measured flow at the C-43 locks show a fast response in water levels and flows.

Irrigation accounts for almost all of the water use in the basin. Water for irrigation purposes is mainly pumped from irrigation canals but a large number groundwater wells are found in parts of the area. Sugar cane, citrus, truck crops and improved pasture are the main crops being irrigated. During dry periods irrigation demands are met by release of water from Lake Okeechobee to C-43. Water is pumped from C-43 upstream into the primary irrigation canals and eventually into minor ditches or directly onto the fields.

1.2 Background and objectives

The Caloosahatchee Water Management Plan project is part of the Lower West Coast Water Supply Plan. The project aims at providing a plan for:

- Adequate supply of water for all existing and future competing uses within the basin.
- Improvements to the functions of natural systems.
- Improvements of surface and ground water quality.

Due to the conjunctive use of surface water and groundwater in the basin and the interaction between surface water bodies and the underlying aquifers an integrated model was chosen to include the total available water resources. More specifically the applied integrated hydrological model (MIKE SHE) is developed in order to:

- Quantify the volume of water used in the basin by irrigation

- Determine the relative contribution of basin runoff, ground water seepage and Lake Okeechobee water to the total basin water resources.

- Provide a planning and management tool for the Lower West Coast Water Supply Plan, which facilitates impact analysis of various water management initiatives.

1.3 Model approach

The ISGM includes the freshwater portion of the basin, which stretches from Lake Okeechobee upstream to the Franklin lock (S-79) downstream. The model area encompasses approximately 1,050 mi^2 (2,720 km^2).

The Caloosahatchee basin may be divided into four primary sub-basins based on surface topography. The Eastern part of the Caloosahatchee basin, which contributes to the flow at Ortona Lock (S-78) and the Western part covering the run-off area between S-78 and Franklin Lock (S-79). Apart from these two major sub-basins the S4 basin in the southeast and Telegraph Swamp catchment in the northwest have been included in the model. S4 drains partly to Lake Okeechobee and partly to the eastern part of the Caloosahatchee basin. Telegraph Creek discharges downstrem S-79 but to account for the cross boundary overland flow, which has been reported in the northeastern part of the model area during storms, the basin has been included.

The basin boundaries were originally established as part of the C-43 canal design. Land elevation changes and drainage schemes have changed the drainage patterns and boundary modifications have been made accordingly (Ref. 2).

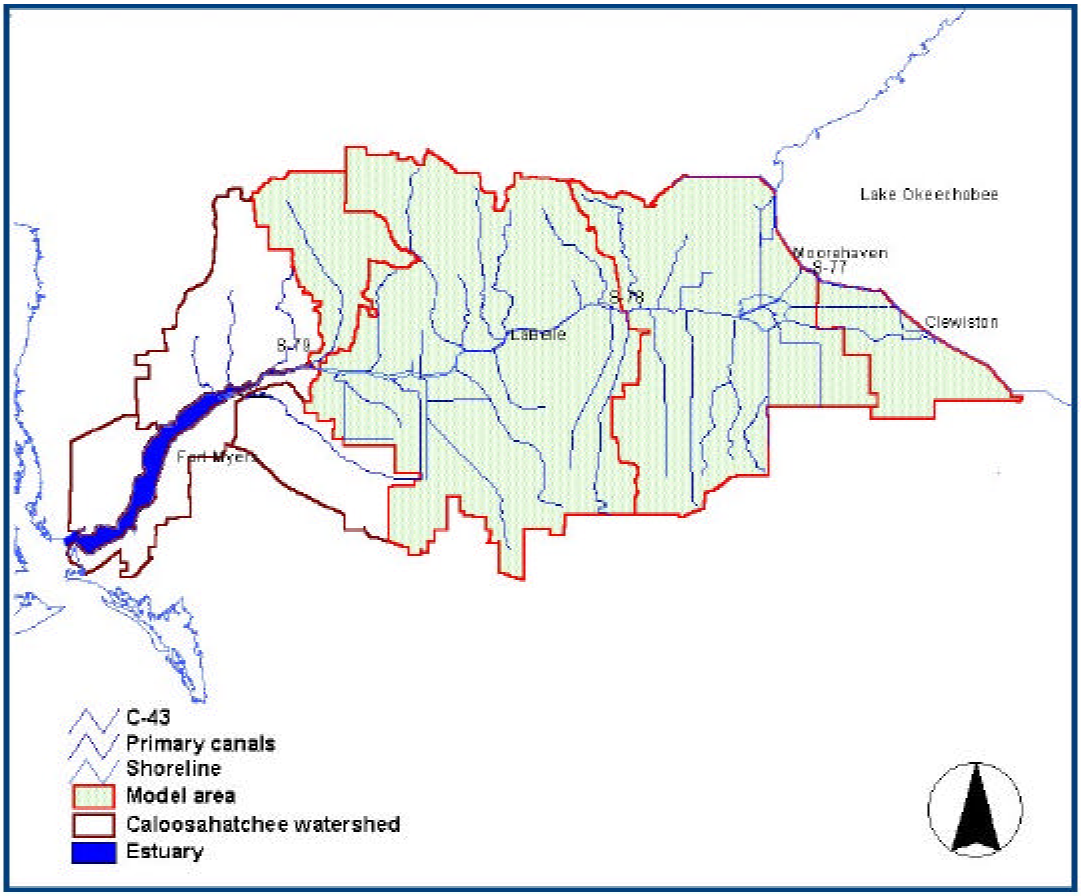

Figure 3 The Caloosahatchee basin and the ISGM model area

Due to the integrated nature of the surface water and groundwater resources an integrated approach has been adopted. The model must have the capability of simulating major flow processes within the basin:

- Overland sheet flow and depression storage
- Infiltration and storage in the unsaturated zone
- Dynamic exchange between unsaturated zone-groundwater (recharge)
- Dynamic exchange between aquifers-rivers/canals (seepage)
- Groundwater flow, storage and potential heads
- River/canal flow and water levels
- Evapotranspiration losses
- Effects of drainage
- Effects of irrigation water allocation

To cover all processes with one model the MIKE SHE modeling system was selected. The model is an integrated and distributed, physically based, finite difference model. MIKE SHE comprises a number of flow modules, which may be combined to describe flow within the entire land based part of the hydrological cycle or tailored to studies focusing of areas of particular interest.

For the Caloosahatchee model the following model components have been applied:

Table 1 Model components applied for Caloosahatchee ISGM

Model component	Simulates	Fully dynamic coupling with:	Dim.	Governing equation
MIKE SHE OL	Overland sheet flow and water depth, depression storage	MIKE SHE SZ, UZ and MIKE11	2-D	Saint-Venants equation (kinematic wave approximation)
MIKE 11	Fully dynamic river and canal hydraulics (flow and water level)	MIKE SHE SZ, OL	1-D	Saint-Venants equation (dynamic wave approximation)
MIKE SHE UZ	Flow and water content of the unsaturated zone, infiltration and groundwater recharge	MIKE SHE SZ, OL	1-D	Richardsons equation / gravitational flow (no effects of capillary potential)
MIKE SHE ET	Soil and free water surface evaporation, plant transpiration	MIKE SHE UZ, OL	-	Kristensen&Jensen / Penman-Monteith
MIKE SHE SZ	Saturated zone (groundwater) flows and water levels	MIKE SHE UZ, OL and MIKE11	3-D	Boussinesqs equation
MIKE SHE IR	Irrigation demands (soil water deficit) and allocation (surface water/ groundwater)	MIKE SHE SZ, MIKE 11	-	-
MIKE SHE PP	Pre- and postprocessing	-	-	-

The model area is discretisized into a number of computational cells for the numerical solution of the governing equations. The spatial scale of MIKE SHE may be chosen either to address regional basin issues or to do local detailed studies focusing on sub-basins.

The Caloosahatchee model may be characterized as a regional study implying that the purpose of the model is to simulate the water resources in an overall perspective. A finer grid resolution may be desirable to describe the basin in further detail, but the computer processing time and the density of available input data should be considered. As a compromise between detailed model output and computer capacity a 1500 ft (457 m) computational grid was applied. Parameters and input data are lumped to represent the average conditions within the computational cells.

The time scale of the surface water regime and the groundwater regime are different. The model allows use of different time steps for calculation of e.g. river/canal flow and groundwater flow. The river hydraulics model is run in 15 minutes time steps, while overland flow is solved in 6 hours time steps and groundwater flow calculations are carried out once a day.

2 INPUT DATA AND MODEL DEVELOPMENT

2.1 Meteorological data

2.1.1 Rainfall

The rainfall distribution is highly variable in both time and space. Local thunderstorms account for considerable rainfall volumes. Accumulated rainfall from the stations in the basin and the surrounding areas do not show a clear geographical pattern and the total rainfall at the stations is generally determined by local weather phenomena.

Rainfall data from 16 stations (Alico,Alva Far,Corkscrew,Devils Garden,Fort Myers, Immokalee,Keritow,Lake Okeechobee,LaBelle,Palmdale, Punta Gorda, S131, S78, S79,South Lee County,Whidden) have been collected for the model. The data were converted into the MIKE SHE timeseries format. From the 16 stations 9 stations were selected by SFWMD to represent the rainfall input in the model area. The measured time series were gap-filled by transferring values from neighboring stations. The rainfall input for the model was spatially distributed according to Thiessen ploygons.

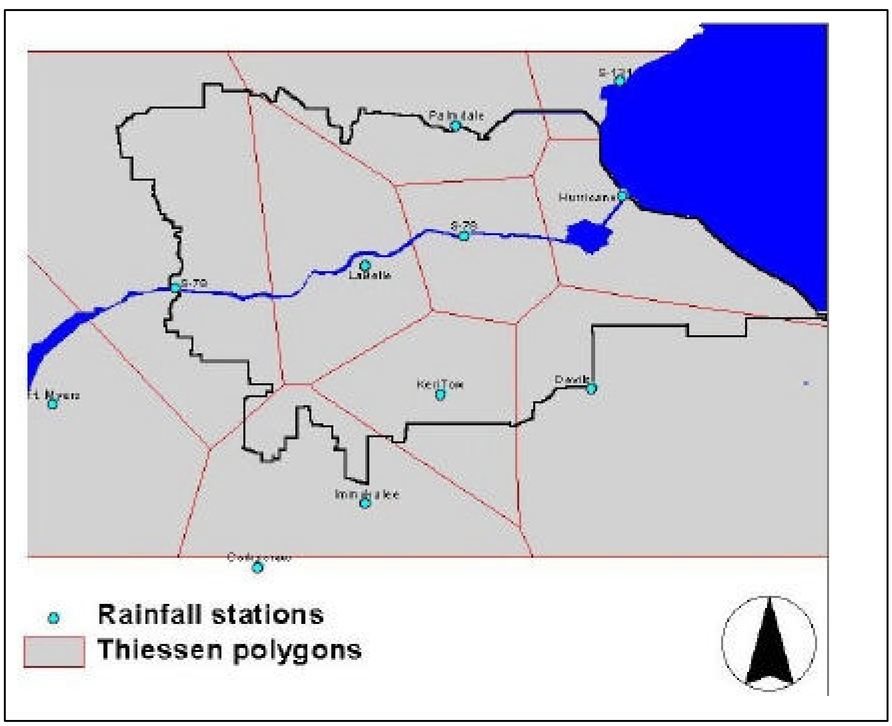

Figure 4 Rainfall distributed by Thiessen Polygons

The input rainfall data are daily values (converted into the general MIKE SHE input unit - mm/h). Weight factors are calculated as the Thiessen polygon area associated with each rainfall station divided by the catchment area for S-78 and S-79. (*Table 2*) show that Devils Garden, Hurricane Gate, Palmdale, S-78 and Keri Tower are the dominant stations with respect to total rainfall input to the model area.

Table 2 Rainfall area weight factors for the Caloosahatchee model

Station	Time series record no.	Area weight factors at S-78 (%)	Area weight factors at S-79 (%)
Devils G.	2	23.3	9.3
Hurricane G.	4	37.8	15.2
LaBelle	5	0.0	21.1
Palmdale	6	10.7	8.4
S-131	8	2.0	0.8
S-78	9	18.3	11.8
S-79	10	0.0	19.2
Immokalee	11	0.0	3.0
Keri T.	12	7.9	11.2
Total		100.0	100.0

The total rainfall can be calculated from the measured rainfall and the area weight factors (Table 3 and Table 4).

Table 3 Monthly rainfall in the ISGM model at S-78 (inches), 1980-1996

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	3.4	1.5	1.7	4.7	2.5	2.7	6.9	5.9	5.4	1.2	3.1	0.7	39.5
1981	0.8	1.7	1.5	0.3	2.3	5.9	4.2	9.9	3.6	0.9	1.9	0.2	33.3
1982	0.6	2.4	5.0	3.0	10.0	12.9	9.7	4.6	6.1	4.2	0.5	1.0	60.1
1983	4.2	9.3	5.2	1.8	0.8	8.9	4.5	6.6	5.1	4.4	2.1	3.2	56.0
1984	0.3	3.4	5.1	2.9	7.0	6.1	9.7	5.0	4.7	0.5	2.9	0.1	47.8
1985	0.4	0.4	1.6	5.5	2.0	6.2	5.3	4.7	7.3	2.1	1.0	2.1	38.4
1986	1.9	1.0	5.6	0.2	1.6	11.6	4.6	9.1	4.2	5.6	0.4	2.8	48.7
1987	1.6	2.0	6.6	0.4	2.4	3.5	5.4	3.2	8.5	5.4	9.5	0.4	48.9
1988	2.2	2.5	3.6	1.0	1.6	4.0	8.5	9.4	1.4	0.7	5.1	0.7	40.8
1989	1.4	0.2	3.7	4.1	2.0	7.3	7.4	5.1	7.1	2.9	0.3	2.2	43.8
1990	0.8	2.7	0.9	2.5	3.1	5.2	8.2	11.7	3.1	2.9	0.8	0.2	42.0
1991	6.0	1.1	3.2	3.5	7.5	7.9	9.7	6.9	3.5	4.3	1.9	0.2	55.8
1992	1.6	3.7	3.2	2.3	1.3	19.3	4.1	8.7	3.2	0.8	1.7	0.7	50.5
1993	5.6	1.9	2.8	2.1	2.2	4.4	5.5	5.9	6.6	6.1	1.1	1.1	45.3
1994	3.5	2.6	2.5	3.2	4.1	6.2	5.7	5.5	10.6	3.6	3.4	4.9	55.8
1995	3.5	2.3	4.0	3.4	2.0	8.5	12.8	9.2	5.4	10.2	0.3	0.5	62.0

Table 4 Monthly rainfall in the ISGM model at S-79 (inches), 1980-1996

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1980	2.7	1.5	1.4	4.0	3.2	2.2	7.1	7.2	4.8	1.3	3.3	0.6	39.5
1981	0.8	1.8	1.5	0.2	1.9	6.5	5.4	11.4	4.1	0.5	1.5	0.3	36.0
1982	0.8	1.7	4.4	3.2	9.4	12.7	8.1	5.3	7.0	3.9	0.4	0.8	57.8
1983	3.9	10.3	6.3	1.7	0.7	11.2	5.0	7.6	5.7	4.7	2.3	3.7	63.2
1984	0.3	3.2	4.8	2.5	7.0	7.0	10.5	5.1	5.0	0.6	3.1	0.2	49.1
1985	0.5	0.4	1.7	4.3	2.1	7.2	5.8	7.3	7.6	2.3	1.3	1.4	42.0
1986	2.0	1.2	4.5	0.3	1.8	11.2	5.6	8.7	4.7	4.9	0.4	3.9	49.2
1987	1.6	2.5	7.5	0.3	3.4	4.9	8.0	4.6	7.3	5.9	7.9	0.5	54.4
1988	2.2	2.4	3.9	1.8	2.6	4.0	8.2	12.3	2.0	0.7	4.9	0.8	45.7
1989	1.2	0.4	3.5	3.8	1.2	9.5	8.0	8.6	6.3	3.5	0.4	2.0	48.4
1990	0.6	3.1	1.1	2.8	3.2	6.2	7.7	11.3	3.4	3.0	0.7	0.2	43.4
1991	6.1	1.2	2.2	3.4	8.2	8.8	10.1	7.8	5.5	3.9	1.7	0.2	59.1
1992	2.0	4.1	3.3	3.3	1.2	19.5	5.3	9.2	4.3	1.0	2.1	0.7	56.0
1993	6.1	2.0	3.2	2.1	2.2	5.6	6.9	7.0	7.2	6.3	0.8	0.9	50.3
1994	3.1	2.4	2.1	3.3	3.3	6.3	5.3	7.3	9.8	3.9	3.1	4.2	54.1
1995	3.6	2.1	2.7	3.4	1.7	10.6	14.8	9.3	6.0	11.0	0.3	0.5	66.0

The average rainfall for S-79 is 51 inches/year for the period 1980-1995 and slightly lower (48 inches/year) for the eastern part of the basin (S-78). The driest year was 1981 (36 inches/year) and the wettest 1995 (66 inches/year). The highest rainfall is seen in the period June-August and the lowest in December-April.

2.1.2 Evapotranspiration

The model simulates the actual evapotranspiration rate. It is calculated at each time step as a percentage of the potential evapotranspiration rate. Measured time series of potential evapotranspiration rates must thus be specified as part of the model input. Two sets of potential evapotranspiration data exist for the Caloosahatchee basin: Measured pan evaporation data and Pennmann estimates based on meteorological data (solar radiation, temperature, humidity and wind speeds).

The data are primarily used to simulate soil or free water surface evaporation and plant transpiration. Consequently a crop vegetation specific potential evapotranspiration rate is needed (see 2.4). The Pennmann data are thus considered to be the best suited data and time series from three stations have been applied(LaBelle, Fort Myers and Moorehaven).

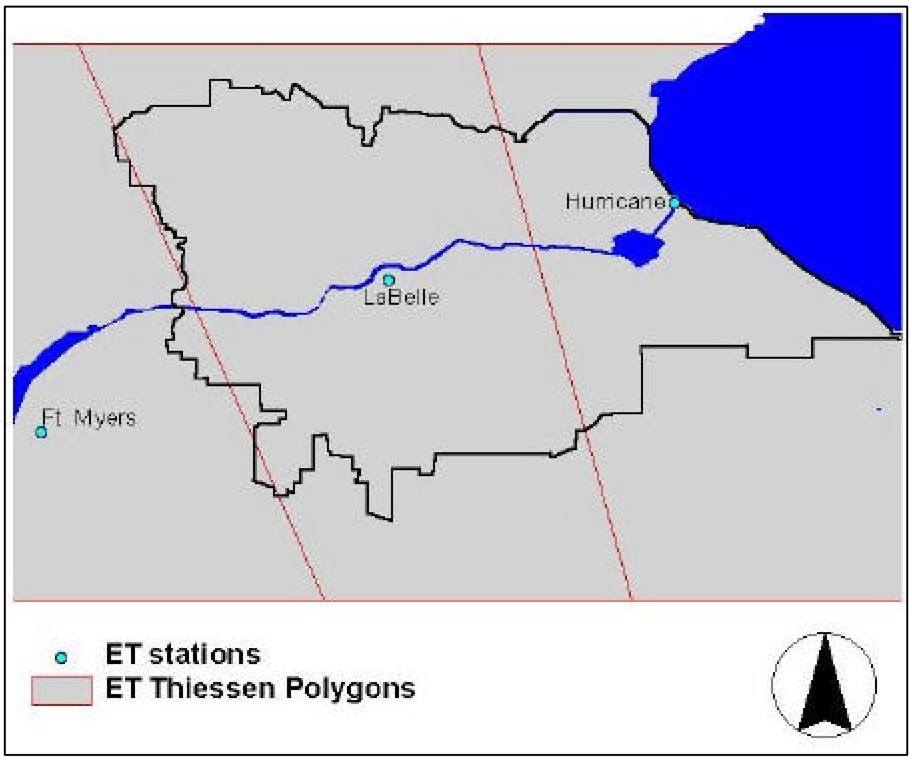

Figure 5 Distribution of potential evapotranspiration rates by Thiessen polygons

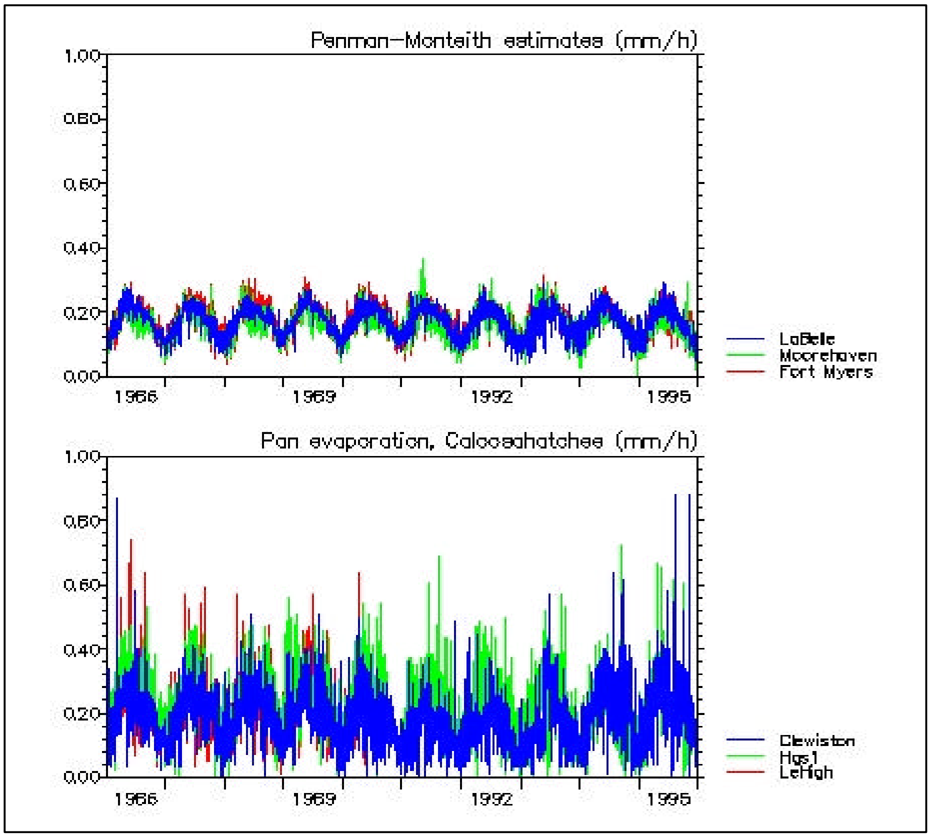

Figure 6 Time series of pan ET and Penman estimates of potential ET rates (mm/h)

2.2 Groundwater

2.2.1 Geological model

Dynamic groundwater flow and potential heads are simulated by MIKE SHE. The modeling system requires a fully 3-dimensional geological model describing the extent, thicknesses and elevation of al major geological units including both aquifers, aquitards and confining layers.

The surficial and intermediate aquifer system has been represented in the conceptualized geological model. The aquifer system includes:

- Water table aquifer
- Tamiami aquifer
- Sandstone aquifer
- Upper Hawthorn

These geological layers are assumed to account for the exchange with the river and canal network and to constitute the major source of groundwater in the model area. The deeper Floridian Aquifer system is not considered to be recharged in the model area or add to the water available in the above aquifer systems. Regional potential head maps indicates that the primary zone of recharge of the Floridian aquifer is northeast of the model area. The assumption has been mad in accordance with previous groundwater studies in the area.

Lithological information in terms of borehole logs extracted from the USGS, Florida, borehole database have been applied to establish a geological model as part of previous groundwater studies in Lee, Hendry and Collier County (*Ref. 4*). The data have been interpreted and processed during these studies and have been made available as GIS coverages of borehole locations and corresponding elevations. Borehole data from Charlotte and Glades counties are not available and the layer thicknesses have been extrapolated from Lee and Hendry counties into this area.

Digital maps of elevation of the individual geological layers and lenses have been generated from the discrete borelog information. The Tamiami and the Sandstone aquifer cover only the eastern and the weatern parts of the model area respectively. Irrigation well logs indicate that the two aquifers serve as the primary source of groundwater in the basin. The extent of the two aquifers has been assessed partly from the lithological information from boreholes partly from irrigation wells. The water table aquifer and the Upper Hawthorn layers are global found throughout the model area.

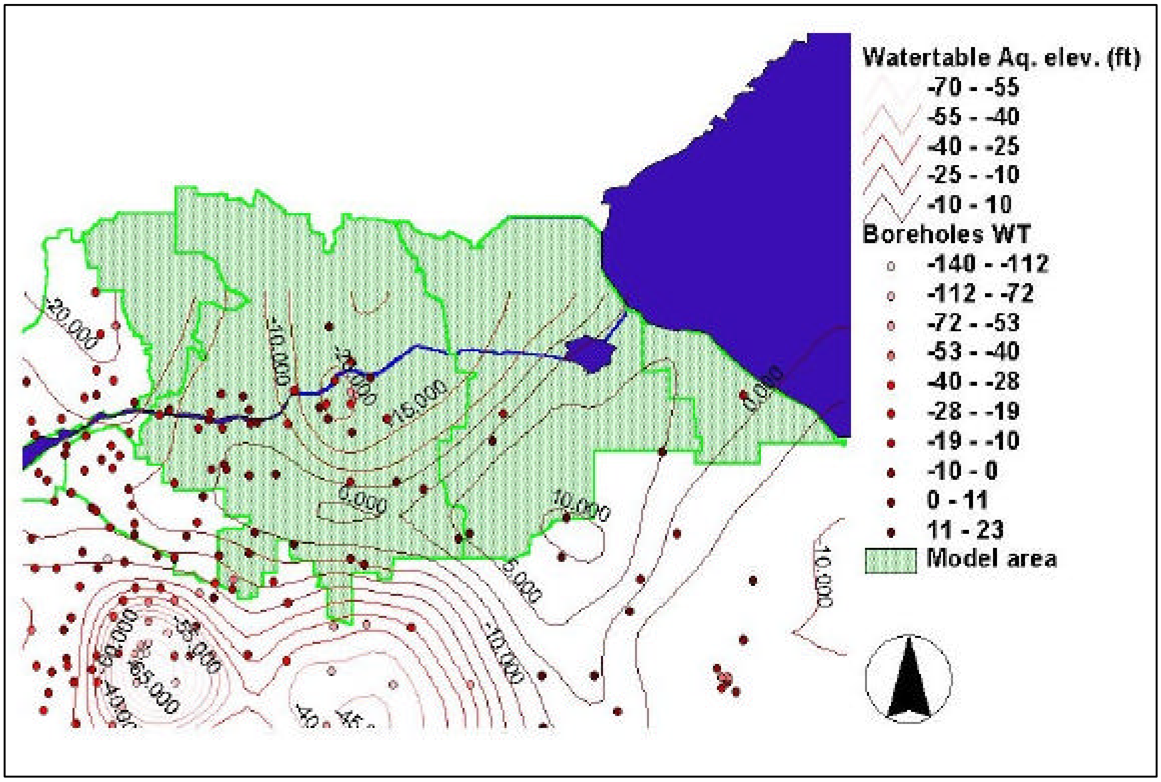

Figure 7 Water table aquifer - extent and elevation

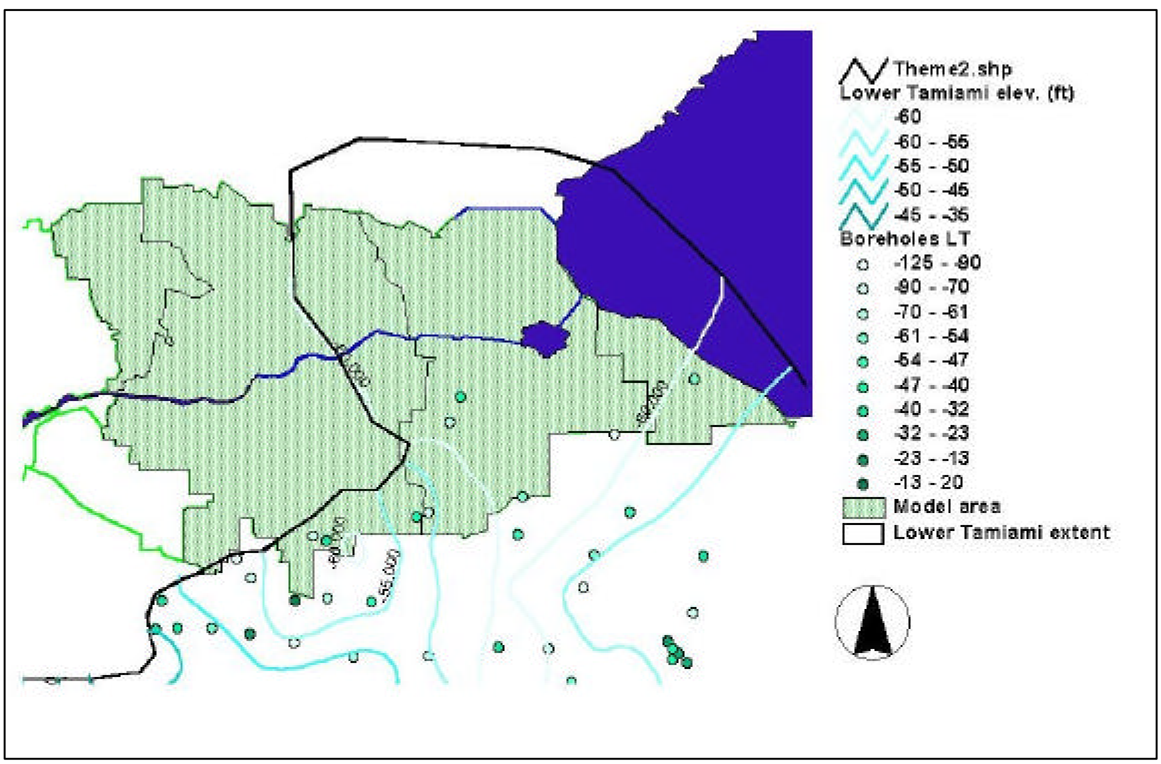

Figure 8 Tamiami aquifer - extent and elevation

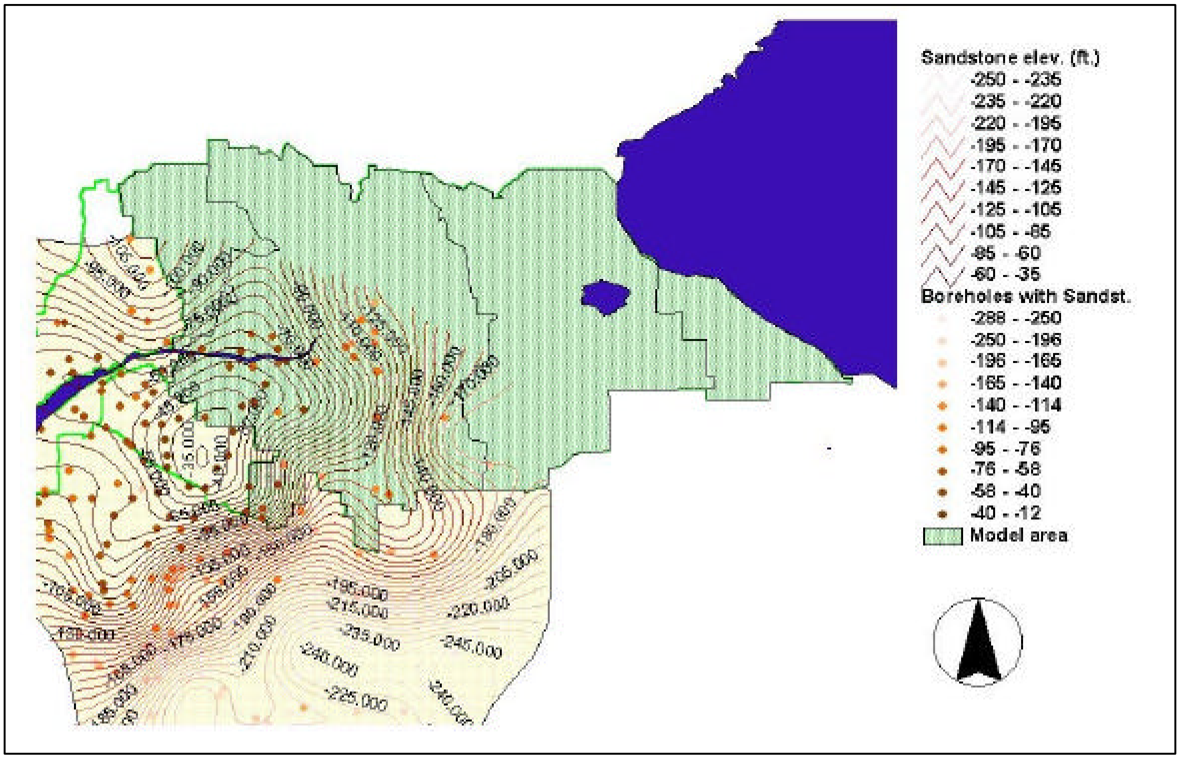

Figure 9 Sandstone aquifer - extent and elevation

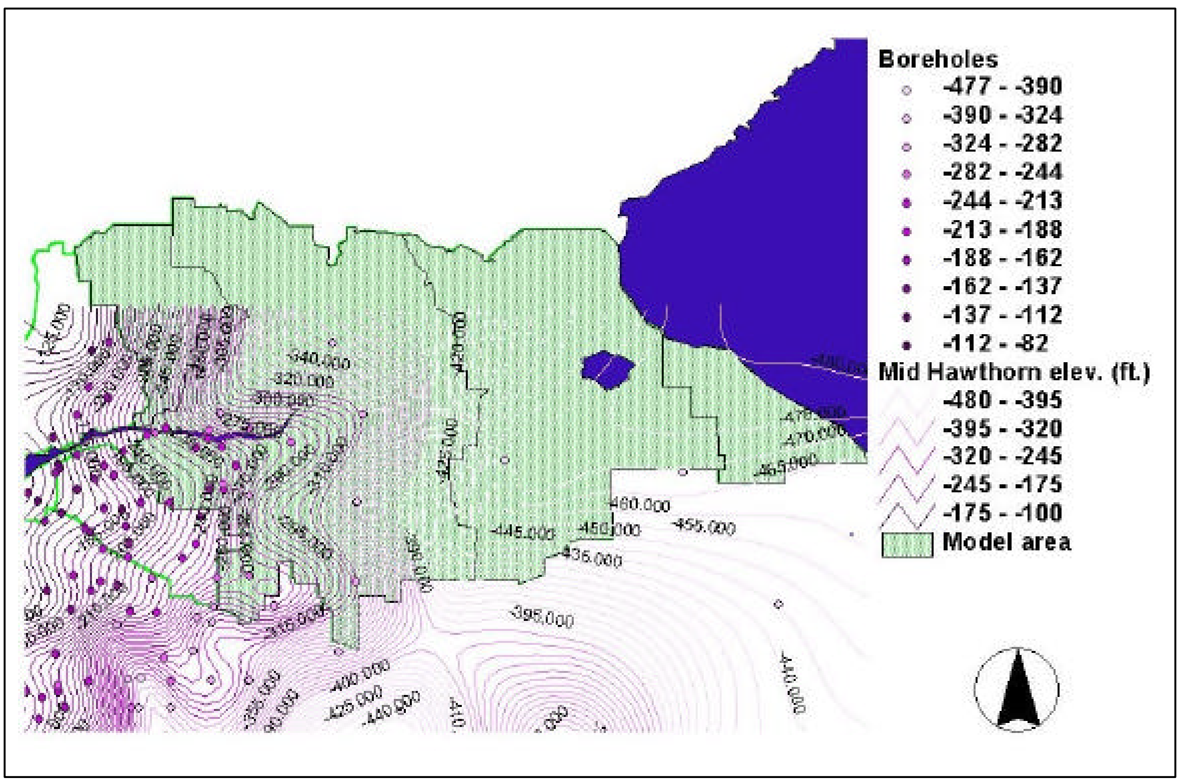

Figure 10 Upper Hawthorn - extent and elevation

2.2.2 Hydrogeological parameters

The aquifers consist mainly of marine sediments of sand, sandstone, limestone and shells. The layers generally have high porosities and are high to medium permeable. The Hawthorn aquifer contains finer silty and clayey sediments. The hydraulic properties of the layers must be specified for the groundwater component. The hydro-geological parameters to be specified for each layer of the model include:

- Horizontal and vertical conductivities
- Confined and unconfined storage coefficients

Pump test data are available at 26 locations inside the model area (Figure 11). The pump test data have been associated with either the upper aquifer sequence (the water table aquifer and the Tamiami aquifer) or the intermediate aquifer sequence (mainly the sandstone aquifer). The maximum drawdown has been observed in nearby wells pumping at a constant rate. The pump test analysis have been based on different methods - mainly Hantush-Jacob or Cooper. From the pump test analysis transmissivities, storage coefficients and in some cases leakage coefficients have been derived.

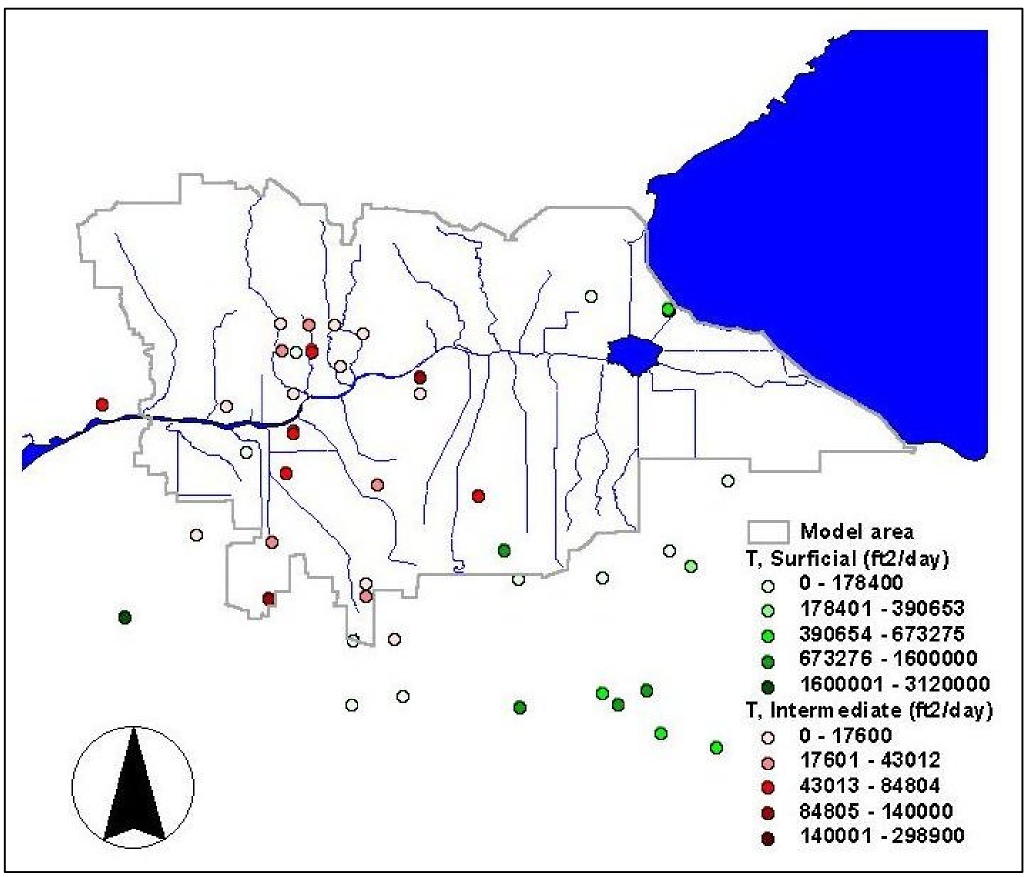

Figure 11 Pump test locations and hydraulic parameters

The following ranges of aquifer properties are found from the pump test data inside the model area :

Table 5 Hydrogeological properties derived from pump tests within the model area

Surficial aquifer	No. of sites	Max.	Min.	Average
Transmissivity (ft^2/day)	7	938368	9500	332849
Storage coefficient	7	1.6 e-1	4.5 e-5	2.0 e-2
Leakage	3	4.4 e-2	1.3 e-7	9.0 e-3
Intermediate aquifer	No. of sites	Max.	Min.	Average
Transmissivity (ft^2/day)	22	298900	1213	59894
Storage coefficient	18	7.0 e-3	2.0 e-5	8.4 e-4
Leakage	17	2.9 e-1	2.8 e-6	1.2e-2

The wide range of transmissivity data reflects the varying composition and properties of the screened geological formation. The pump test carried out for the clastic sandstone or the lower Tamiami generally shows higher transmissivities than wells associated with unnamed or unknown aquifer

The density of data is considered insufficient to produce distributed maps of the aquifer properties for each geological layer of the model The pump test data and previous groundwater studies have been used to establish ranges of the parameters. The parameters have been distributed by division into zones i.e. subdivision of the model area into sub-areas with uniform parameter values.

2.2.3 Boundary conditions

Groundwater boundary conditions are specified for all layers in the model. For the upper layer it is assumed that surface water and groundwater divides coincide and subsequently a no flow boundary has been applied. The surface water divides have been subject to further analysis in order to incorporate man made changes of drainage paths. The surface water boundary is uncertain in some parts of the basin and flow directions may change depending on local water level changes in response to storms. Consequently some uncertainty is associated with groundwater boundary as well. The flow, which may occur across the boundary, is most likely insignificant with respect to the water balance.

A no flow boundary has been applied or the lower part of the aquifer system as well with some modification on the southern boundary. Operation of irrigation groundwater pumps have been reported to cause drawdowns in this area. They are believed to cause cross boundary groundwater flow which depending on the head gradient is flows in or out of the model area. 3 observation wells located at the southern boundary show the water table fluctuations including the effects of drawdowns. These time series have been applied to generate the dynamic head boundary used in the model for the lower aquifer.

2.2.4 Groundwater withdrawals

Well location and time series of pumping rates may be specified as part of the input for the groundwater component. There is no significant industrial water use or municipal water supply in the model area.

Withdrawal of groundwater is not specified as part of the input for the groundwater component, but is determined as a function of actual irrigation demand and the availability of surface water at irrigation outtake points. Surface water is generally considered to be the primary source of irrigation water. If the surface water supply is insufficient at a particular point during the simulation groundwater is defined as second priority. The actual groundwater withdrawal for a given irrigated area at a given time is thus depending on the irrigation demand calculated on basis of field conditions, e.g. soil water deficit of the root zone and if the demand can be covered solely by applying surface water.

The allocation of groundwater for irrigation can be specified to take place from individual wells or it may be assumed uniformly distributed within the irrigation area. The storage capacity and the transmissivity of the aquifer may limit the groundwater withdrawal. Demands may not be met at one time step of the simulation if the available volume of groundwater is insufficient due to a locally dried out layer or if the withdrawal rate exceeds the rate at which the point of withdrawal is replenished by inflow from the surrounding aquifer.

Comparing the irrigated land coverages and the location and density of permitted ground water wells no irrigation takes place in the south central part of the model area despite a high concentration of existing or projected wells. More details on use of groundwater for irrigation is given in the irrigation module description.

2.2.5 Groundwater drainage

Drainage flow and interflow constitutes an important contribution to the river run-off in the Caloosahatchee basin. The observed river flow hydrograph response to rainfall indicates a relatively rapid response following rainfall events. Rising water tables are effectively lowered by the drainage system. Due to the dense network of ditches and tertiary canals, operation of the drainage pumps in agricultural areas and the hydraulic structures of the drainage canals, excessive volumes of runoff and groundwater is quickly routed into the primary drainage canals adding to downstream peak flows in C-43. The time lag is generally small for the Caloosahatchee basin.

The hydrodynamic MIKE11 model is applied to simulate the flow and water level dynamics in the schematized primary canals and second order drainage/irrigation canals. Higher order canals and ditches are not represented in the river hydraulics model due to the spatial scale of the computational grid (1500 ft) and the regional scope of the model. The higher order drainage system is dense in agricultural areas and acts effectively to reduce the water tables and prevent water logging in cropped areas. Following rainfall events, high infiltration rates, causes an increase in the groundwater tables. Due to high hydraulic contact between aquifer and canals and the operation of pumps the water tables if rapidly reduced and the water volume is discharged through the drainage network.

To account for the drainage discharge in the basin the drainage component of the MIKE SHE groundwater module is included. Drainage is described through:

- Drainage codes - areas considered to be drained.
- Drain levels - distributed maps of effective drainage levels i.e. groundwater table elevation above which drainage flow occurs.
- Drainage time constant
- Drainage options - routing of drainage water from drain levels, directly to rivers

The drain code map describing drained and non-drained areas has been derived from GIS coverages of the entire canal network provided by SFWMD. Depending on the density of higher order canals and the distance from each grid cells to nearby canals the area has been assumed drained or not (Figure12). Floodplain areas that typically are inundated during parts of the simulation period have been defined as non-drained (Telegraph Swamp and Lake Hicpochee).

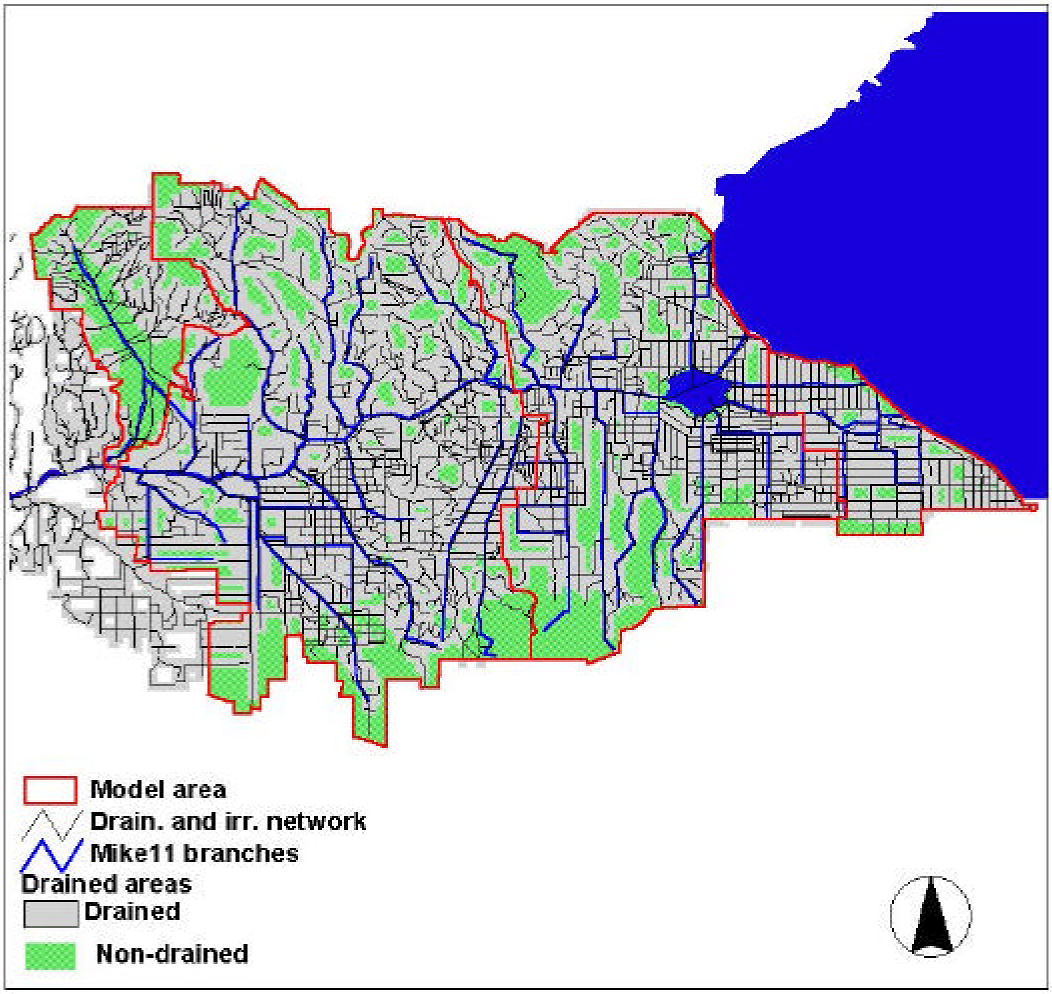

Figure12 Drainage codes and river network for the Caloosahatchee model

Drainage from each computational cell is a function of the drainage level and the time constant. The drainage outflow from the individual cells, Q_{dr}, is calculated from a linear reservoir approximation depending on the actual water table, h_{sz}, above drain level, h_{dr}, and the specified time constant, C_{dr} :

$$Q_{dr} = C_{dr} (h_{sz} - h_{dr}) A$$

where Q_{dr} is calculated in m^3/s , C_{dr} is specified in s^{-1}, the levels in m and the area, A, in m^2.

Drainage levels can not be measured directly in the field. Observed groundwater head of the upper aquifer may provide information on the drainage level, but the spatial variability makes it difficult to transfer discrete information to the entire model area.

Drainage levels have been calculated by subtracting estimated drainage depth from the topography. The effective drainage depths have been specified in the range 1.6 - 4.0 ft. (0.5 - 1.2 m). This range has been chosen considering a number of factors including density and depth of drainage canals and land use. The drainage levels have been modified during calibration in order to simulate peak discharges and at the same time to reduce any drain flow contributions in the dry periods. The plant evaporation from the root zone may serve to reduce the groundwater tables below the drainage level and thereby reduce dry period drainage outflow. In the comparison between rooting depth (specified as part of the evapotranspiration module) and the drainage level it has generally been assumed that drainage levels are at or above the root zone depth. The field operation of drainage pumps in citrus groves suggests that the ground water table is kept within a narrow range to avoid damages to the trees and the crop.

The drainage time constant is the reciprocal value of the mean retention time. Normally the drainage constant ranges from $1e^{-7}$ to $1e^{-3}$ s^{-1}. The delay in drain response described by the time constant affects the peak and recession of the simulated river discharge and is partially a calibration parameter. The numerous canals and the effective drainage schemes imply time constants in the high end of the interval. A uniform value of the drainage time constant, $1e^{-4}$ s^{-1}, has been applied throughout the model area. Considering the characteristics of agricultural areas compared to natural non-developed areas the time constant is expected to vary spatially. Surface water discharge measurements at sub-basin scale would give an indication of the differences in drain response for developed and non-developed areas, respectively. Given the limited flow data and the lumped nature of the time constant a constant value has been applied. The time constant may possibly be distributed from the land use.

When water tables of the upper aquifer rises above the drain level the excess volume is routed to the receiving point. The receiving point for drainage flow may be a depression, a specific location in the river network or the boundary of the model area.

Routing by level implies that a receiving point for the drainage flow in a sub-area of the model is determined from the slope of the drainage level. When specifying drainage depths as a depth below the ground surface the routing will depend on the accuracy and topographical input. For the Caloosahatchee basin drainage patterns are determined partly by pumping and partly by gravity. In densely drained areas the major part of drainage flow is discharged into nearby canals. The drainage options have been used to overrule the routing by levels by assuming that drainage takes place to nearby canals.

The drainage component has been found to strongly affect both river discharges and ground water potential heads. The drainage model parameters have been estimated from available data and general knowledge in the field drainage operation.

2.3 Unsaturated zone

The unsaturated zone extends from the ground surface to the groundwater table. The depth of the unsaturated soil column is dynamic and varies throughout the simulation period. It increases with decreasing groundwater table and decreases when the groundwater table rises. The unsaturated zone may vanish when the groundwater table rises above the ground surface and saturated conditions prevail.

Due to the dynamics of the groundwater table the unsaturated zone properties must be specified from the ground surface down to the lowest ground water level occurring during the simulation period. Hydraulic properties of both the saturated zone and the unsaturated zone must be specified in an overlapping region covering the range of groundwater table fluctuations.

Unsaturated zone flow is important to simulate infiltration, vertical flow through the soil column and recharge to the groundwater. Simulation of the vertical soil water profile requires a detailed description of the actual soil properties. The soil water content is of particular importance with respect to calculation of evapotranspiration losses from the root zone and irrigation demands.

2.3.1 Characteristic soils

Most of the soils of southwest Florida are shallow and sandy with high water tables. They are characterized by high to very high permeability, high porosity and little or no capillary rise. The texture and hydraulic properties of the soils varies both on local and regional scale.

To provide a horizontal and vertical distribution of soil physical parameters characteristic soil types have been identified from landscape classifications. Soils coverage (NRCS SURRGO) was obtained from SFWMD for all six counties (Charlotte, Collier, Glades, Hendry, Lee, and Palm Beach), which are part of the Caloosahatchee basin. There are approximately 70 different soil-mapping units in the basin. Many of these mapping units have similar physical characteristics and are assumed to behave in a hydrological similar manner. For simulation purposes the soils can be classified in different hydrologic response groups. These hydrologic response groups are flatwoods, marshes and ponds, sloughs, depressions, rock (shallow soils on limestone), and unsuitable. The hydrologic response groups are based on the range productivity landscape classes. Six different landscape types have been identified and 5 of those have been related to characteristic soil types. The following soils were selected to represent each landscape class. These soils provide a range in soil physical characteristics typical of the corresponding landscape type.

Table 6 Correlation between landscape type and associated soil type

Landscape type	Soil
Flatwoods	Immokalee
Depressions	Winder
Marsh & Ponds	Sanibel
Rock	Boca
Sloughs	Pineda

Each landscape type is distributed and associated with a standard soil profile including the soil horizons found from field surveys. Each soil type in the profile is represented by it thickness and the soil physical parameters.

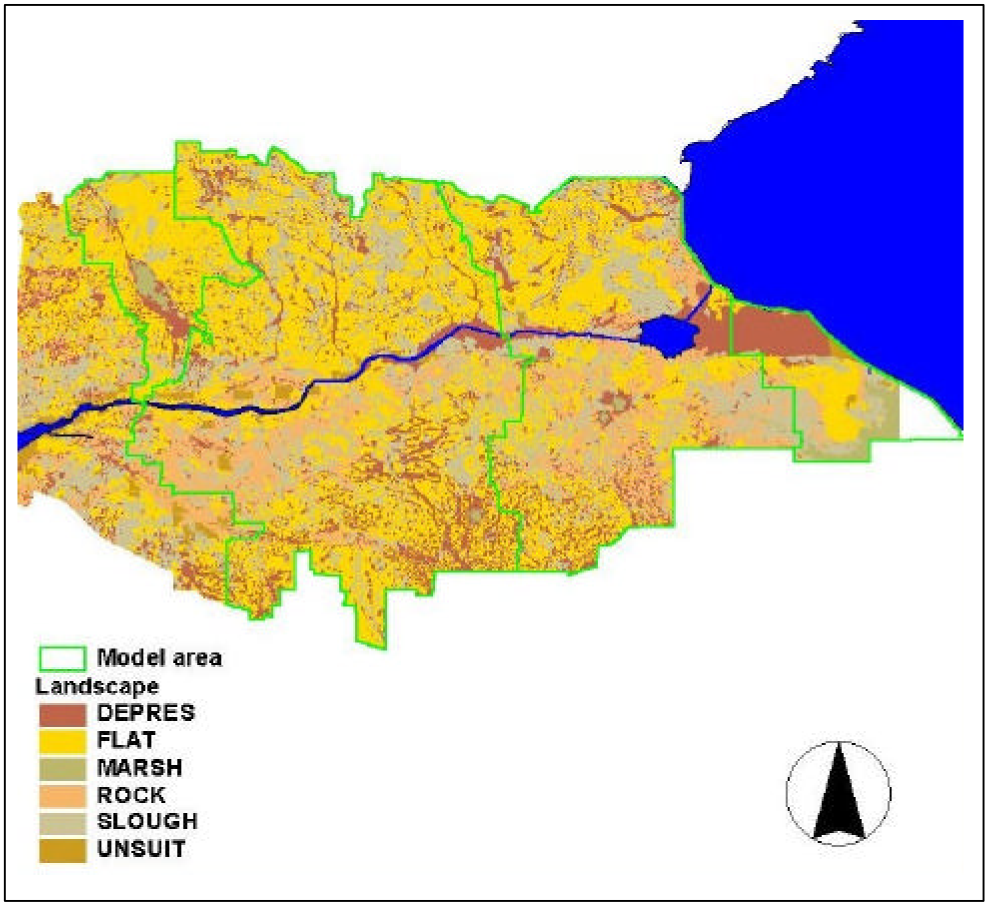

Figure13 Distribution of soil columns in Caloosahatchee basin from landscape types

2.3.2 Soil physical parameters

The soils were evaluated by comparison of the physical characteristics of the soil profile and the hydrologic behavior of the soils. The soil profiles were reviewed for differences in soil texture, hydraulic conductivity, depth to a horizon that would impede percolation and variability of the soil properties. It was determined that all soils were sandy with some fine sands and loam. A MIKE SHE soil physical database were prepared for 55 soils by Southwest Florida Research and Education Center. Each soil sample represents a specific soil sample taken at a specific depth. The database includes retention curves and hydraulic conductivity curves. Soils with large areal extent in the basin were selected for hydraulic simulation using FHANTM2. The data for the simulations were obtained from the DRAINMOD model and data from the county soil surveys. The results indicated that most of the soils behaved in a similar manner with the exception that deeper soils produced less runoff.

Table 7 Soil physical parameters entered into the unsaturated zone database

Profile no. and landscape type	Soil type and depth	Saturated hydraulic conductivity K_s [m/s]	Saturated water content Θ_s [%]	Water content at field capacity Θ_{fc} [%]	Water content at wilting point Θ_w [%]	Residual water content Θ_r [%]
(1) Flatwoods	Immokalee A1 (0.0-0.1 m)	2.0e-4	0.42	0.079	0.03	0.01
	Immokalee AE (0.1-0.23 m)	1.1e-4	0.42	0.095	0.057	0.031
	Immokalee E1 (0.23-0.41 m)	8.6e-5	0.39	0.084	0.025	0.015
	Immokalee E2 (0.41-0.91 m)	1.0e-4	0.38	0.074	0.017	0.01
	Immokalee Bh2 (0.91-1.4 m)	6.1e-6	0.38	0.225	0.07	0.043
	Immokalee Bw/Bh (1.4-23 m)	7.5e-5	0.38	0.112	0.033	0.02
(2) Slough	Pineda E (0.0-0.13 m)	8.0e-5	0.464	0.085	0.033	0.02
	Pineda Bw1 (0.13-0.33 m)	8.0e-5	0.449	0.085	0.023	0.02
	Pineda Bw2 (0.33-0.58 m)	6.4e-5	0.422	0.095	0.009	0.01
	Pineda E1 (0.58-0.91 m)	5.3e-5	0.408	0.076	0.012	0.02
	Pineda Btg/E (0.91-1.37 m)	3.1e-7	0.351	0.31	0.11	0.1
	Pineda Cg (1.37-22 m)	1.1e-6	0.380	0.347	0.162	0.1
(3)Depres sion	Winder A1 (0.0-0.08 m)	3.6e-5	0.374	0.175	0.024	0.014
	Winder E (0.08-0.33 m)	5.7e-5	0.37	0.092	0.008	0.004

	Winder Btg (0.33-0.58 m)	7.4e-6	0.43	0.395	0.153	0.101
	Winder C1 (0.58-0.89 m)	4.1e-6	0.332	0.225	0.038	0.021
	Winder C3 (0.89-21.7 m)	1.9e-6	0.355	0.303	0.107	0.062
(5) Rock	Boca A (0.0-0.08 m)	1.1e-4	0.487	0.088	0.04	0.029
	Boca E1 (0.08-0.23 m)	9.7e-5	0.46	0.080	0.034	0.023
	Boca E2 (0.23-0.36 m)	8.0e-5	0.408	0.064	0.024	0.015
	Boca Bw (0.36-0.64 m)	5.4e-5	0.396	0.071	0.009	0.006
	Boca Btg (0.64-22.64 m)	8.3e-7	0.347	0.0311	0.122	0.071
(6) Marsh	Sanibel Oa1 (0.0-0.12 m)	2.0e.5	0.55	0.715 (?)	0.197	0.2
	Sanibel A1 (0.12-0.23 m)	9.4e-5	0.51	0.370	0.025	0.01
	Sanibel C1 (0.23-0.66 m)	1.4e-4	0.37	0.069	0.013	0.01
	Sanibel C2 (0.66-21.7 m)	1.1e-4	0.38	0.062	0.011	0.01

2.3.3 Model set-up

Vertical flow and water content of the unsaturated soil is calculated using a maximum time step of 6 hours. The computational time steps are automatically updated during the simulation to avoid numerical instability following high rainfall inputs.

The vertical flow in the unsaturated soil column and the water content profile is calculated solving the equation for gravity flow i.e. disregarding capillary effects.

The unsaturated zone does not require specification of boundary conditions. The ground water table of the upper aquifer constitutes the lower boundary for the unsaturated zone within each of the soil columns. The upper boundary may act as a flux boundary when the soil has sufficient infiltration capacity. When the infiltration capacity is exceeded a head boundary is applied depending on overland water depth. When groundwater tables rises above the ground surface the unsaturated zone flow calculations are replaced by the groundwater component.

The vertical flow in the unsaturated zone is calculated in each time step for all of the 12,997 computational columns.

The unsaturated zone classification option of MIKE SHE is used to reduce the total computational time required to solve the unsaturated zone flow in each time step. It allows the user to transfer simulated flow between soil columns of similar characteristics i.e. rainfall, potential evapotranspiration, soil type, land use type and depth to the groundwater table. Because the classification option does not distinguish between flooded/non-flooded areas or irrigated/non-irrigated areas it has not been used for Caloosahatchee ISGM.

2.4 Land use and evapotranspiration

Land use data are primarily used for distributing vegetation characteristics applied for simulation of actual evapotranspiration in MIKE SHE.

Evapotranspiration accounts for the bulk of water losses from the Caloosahatchee basin. The water is lost to the atmosphere reducing the water available for surface and sub-surface runoff. The ET module of MIKE SHE simulates:

- Interception and evaporation from vegetation cover
- Soil and free water surface evaporation
- Plant transpiration from the root zone

The actual rate of evapotranspiration is calculated from (Kristensen and Jensen, ref.6):

$$E_{at} = f_1(LAI) \cdot f_2(\Theta\ ) \cdot RDF \cdot E_{pot}$$

where E_{at} is the actual rate of evapotranspiration, f_1 is a damping function ($0 < f_1 < 1.0$) describing effects of vegetation density (leaf area index, LAI), f_2 a damping function ($0 < f_2 < 1.0$) describing the dependency on soil water content, Θ, and RDF is the root distribution function (vertical distribution of root mass).

The leaf are index, LAI, is calculated as the total leaf area of the vegetation per unit ground surface area. LAI is a measure of the vegetation surface area available for transpiration. LAI may be time varying for seasonal vegetation while perennial vegetation my be considered constant. Harvested crops such as sugar cane and truck crops are described by vegetative stages covering the growth period.

RDF is the percentage of active root mass in a specific depth of the root zone. A rooting depth is specified (extinction depth) and the root mass is distributed vertically by an exponential function. The root mass distribution and the vertical soil moisture profile of the root zone affects the actual evapotranspiration rate in each depth interval of the root zone and as a total integrated for the entire root zone. The rooting depth may be highly variable depending a number of factors climate, soil properties, groundwater table and unsaturated zone soil moisture profile. In MIKE SHE it is specified for each vegetation type (vegetation database).

2.4.1 Land use and vegetation specific data

Leaf area index and root mass distribution are vegetation specific parameters. The distribution of vegetation parameters is based on the identification of the dominant characteristic vegetation/land use types in the basin.

Land use maps are applied to distribute vegetation specific parameters. Land use maps based on aerial photos and field inventories exist for 1988 and 1995 as GIS polygon coverages. The land use in the basin has been classified from SFWMD land use and land cover classification codes. Coverages exist at different level of detail. The highest level (level I) includes agriculture, barren, forest, water bodies, rangeland, urban and wetlands.

Table 8 SFWMD land use and land cover classification code

Level I	Level II
(A) Agriculture	(AC) Sugar cane (AP) Pasture (AM) Groves,….,fruit (AF) Animal production
(B) Barren	(BB) Beaches (BP) Mines, pits (BS) Spoil areas (BL) Levees
(F) Forest uplands	(FE) Coniferous (FO) Non-coniferous (FM) Mixed
(H) Water	
(R) Rangeland	(RG) Grassland (RS) Scrub and bushland
(U) Urban	(UR) Residential (UC) Commercial (UI) Industrial (US) Institutional
(W) Wetlands	(WF) Forested fresh (WN) Non-forested fresh (WS) Forested salt (WM) Non-forested salt (WX) Mixed forested and non-forested fresh

The MIKE SHE GIS module has been applied to export land use maps from ArcView into MIKE SHE grid format and used as input for the evapotranspiration module.

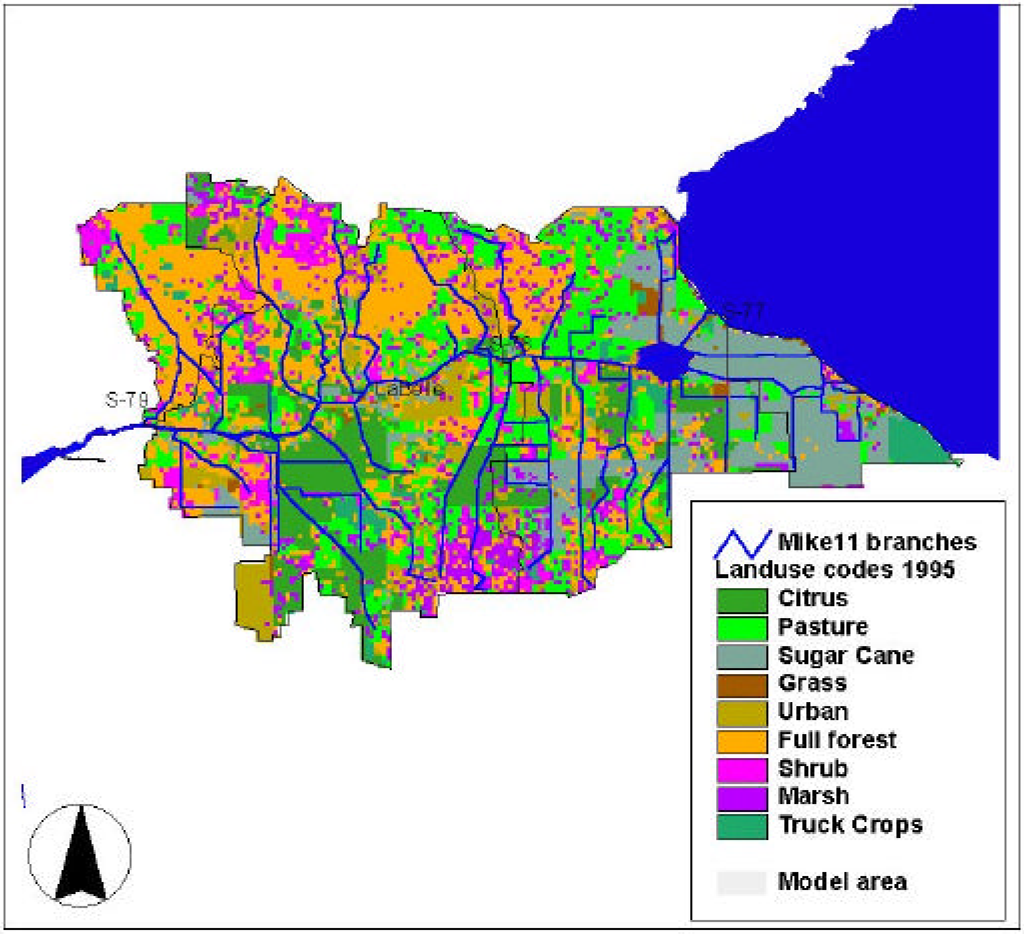

Figure 14 MIKE SHE land cover codes 1995

Table 9 *Land cover types represented in the model and corresponding SFWMD codes.*

Model land cover types	MIKE SHE code	SFWMD land cover classification
Urban	5	U
Citrus	1	AM
Pasture	2	AP
Sugar cane	3	AC
Truck crops	10	-

Grass	4	UR
Dense upland forest	6	F
Sparse upland forest	7	F
Grassland, shrub	8	R
Wetlands, marsh	9	W, H

For each vegetation/land cover type a set of parameters have been entered in the MIKE SHE vegetation database. The parameters include empirical constants used in the equations describing actual evapotranspiration (C_1, C_2, C_3, C_{int}, A_{root}) and time series for RDF, LAI, Kc (crop coefficient) and irrigation requirements. The parameters are given at each growth stage of the crop or vegetation.

RDF and LAI has been estimated for each type of vegetation. Leaf area index values vary within each land use/cover classification. The range is due to the wide variability of the cover included in each class. However, there is insufficient information to split these classes into more specific classes and no field data have been available. The LAI values applied ranges from 1.0 to 6.0.

Similar to LAI the rooting depth varies with vegetation type, soil type, local water tables and drainage. The distribution of root mass with depth varies for different vegetation types and within each vegetation class. Maximum rooting depth and effective rooting depth may differ significantly and the active root mass may vary with the adaptation to varying field conditions (sufficient irrigation or drought). The regional modeling scale and the complexity of root mass distribution does not allow description of the local variation. The RDF parameter is thus to be seen as partly physically based relating to actual rooting depth and partly lumped representing overall vegetation characteristics in each 1500 ft. grid cell. Estimated values in the range of 1.6 - 4.9 ft. (0.5 -1.5 m) have been applied.

Table 10 Land use and irrigation

Land use	Irrigation method	Irrigation source
Urban	None	None
Citrus	Micro-spray	Canals/GW wells
Sugar cane	Subsurface	Canals/GW wells
Truck crops	Micro-spray	Canals/GW wells
Pasture	None	None
Grass	None	None
Dense forest	None	None
Sparse forest	None	None
Grass, shrub	None	None
Wetlands, marsh	None	None

For more details on the irrigation component of MIKE SHE see chapter 2.7 .

2.5 Overland flow

Overland sheet flow occurs when the water depth on the ground surface is larger than zero. Ponding of water at a specific location is a result of:

- Insufficient infiltration capacity of the unsaturated soil column
- Ground water tables rising above ground
- Overland flow from neighboring areas
- Drainage flow to low-lying areas

Due to high infiltration rates and moderate to high horizontal conductivities of the upper aquifer significant overland flow occurs only for the basin in general during storms. The duration of inundation is longer at wetlands covering smaller parts of the basin, but the topography of such areas does not promote overland flow.

2.5.1 Surface slope

The over land flow direction and velocity is determined by the ground surface slope. The input surface topography map is based on 5 feet elevation contour maps supplemented by discrete spot elevations. The data has been collected and processed by SFWMD. The basic data and the derived topographical model are available in GIS coverages. A 500ft map has been created as input for the model by interpolation.

The model area is relatively flat with little topographical relief. Consequently a topographical model based on 5 ft. contours will not be fully represent the depression storage and flow direction in the relatively flat central parts of the basin. Isolated wetlands and ponds may not be described in 5-foot contour resolution and the 1500-ft. computational grid resolution. To investigate the overland flow and storage in more detail a finer computational grid is required.

Overland flow only occurs during storm events. More important is the depression storage i.e. low lying areas receiving overland flow or drainage flow. The surface detention volume is describes by the topography. Ponding water accumulates as depression storage until the water level exceeds topographical thresholds separating the depression from surrounding areas. Ponded water may also infiltrate limited either by the infiltration capacity of the underlying unsaturated zone, or when the soil is entirely saturated, the leakage coefficient between the overland component and the saturated zone

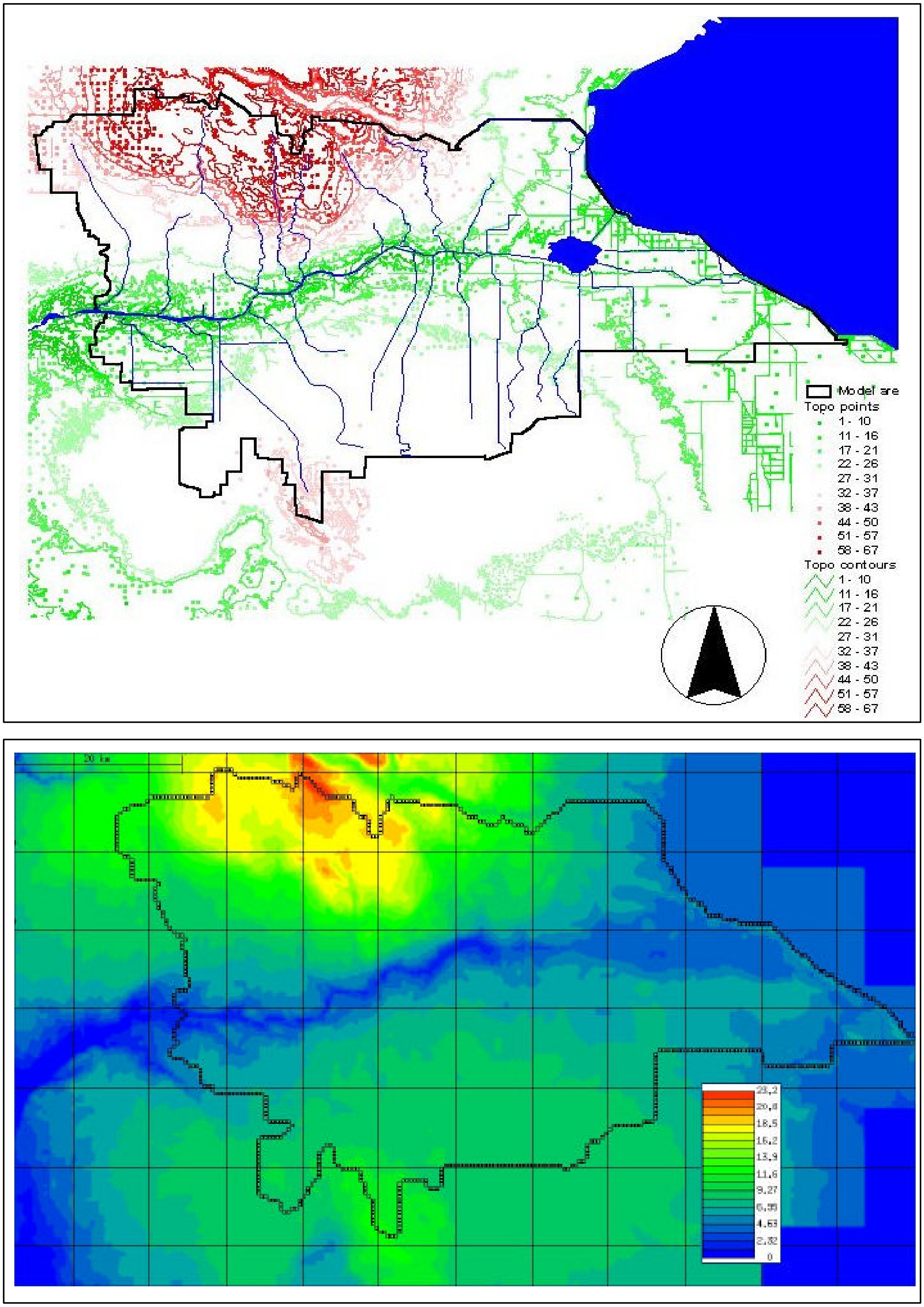

Figure 15 MIKE SHE digitised data and interpolated topographical model (elevations in meters).

2.5.2 Model parameters

The governing equation for overland flow (2-D Saint-Venant) requires specification of a Manning number, detention storage and a leakage coefficient. The Manning number describes the ground surface resistance flow within each computational cell and it depends mainly on land use. A uniform value of 10 $m^{1/3}/s$ has been used. Detention storage is a threshold value that describes at which overland water depth flow is initiated. It depends on surface properties, which may vary within a short distance. Distributed average values for each computational cell may be given. Here a uniform value of 0.4 inches (10 mm) has been applied. Exchange of flow between overland and the groundwater may take place when the soil is completely saturated. The leakage coefficient is used to describe the hydraulic contact between ground water and overland flow. A uniform value of $1 \cdot 10^{-6}$ s^{-1} is used.

2.5.3 Simulation

Overland water depth and flow velocities are calculated in maximum time steps of 6 hours. The time step is reduced at high rainfall intensity.

2.6 Rivers and canals

Flows and water levels are simulated within all major drainage and irrigation canals in the basin. MIKE11 is a fully unsteady river hydraulics model, dynamically coupled to MIKE SHE. This implies that the integrated modeling system fully dynamically accounts for exchange of water between the river and other model components. In each time step the exchanged volumes are updated in all computational points of the model. Inflow and outflow from the river may take place as groundwater seepage (calculated from simulated water level differences between the aquifers and the river reaches), overland flow (surface runoff driven by actual overland water depths and surface slope) and drainage flow (groundwater drainage flow routed to rivers/canal network).

2.6.1 River network

The Caloosahatchee River (C-43) and its major tributaries have been included in the river hydraulics model (MIKE11). Due to the lack of cross section data and the limitations on the number of computational nodes the canals represented directly in the Mike11 model have been chosen from the following criteria:

- All major irrigation canals in order to describe the allocation of irrigation water
- All major drainage canals and natural streams contributing to C-43 discharge
- Rivers/canals draining major swamps or wetlands

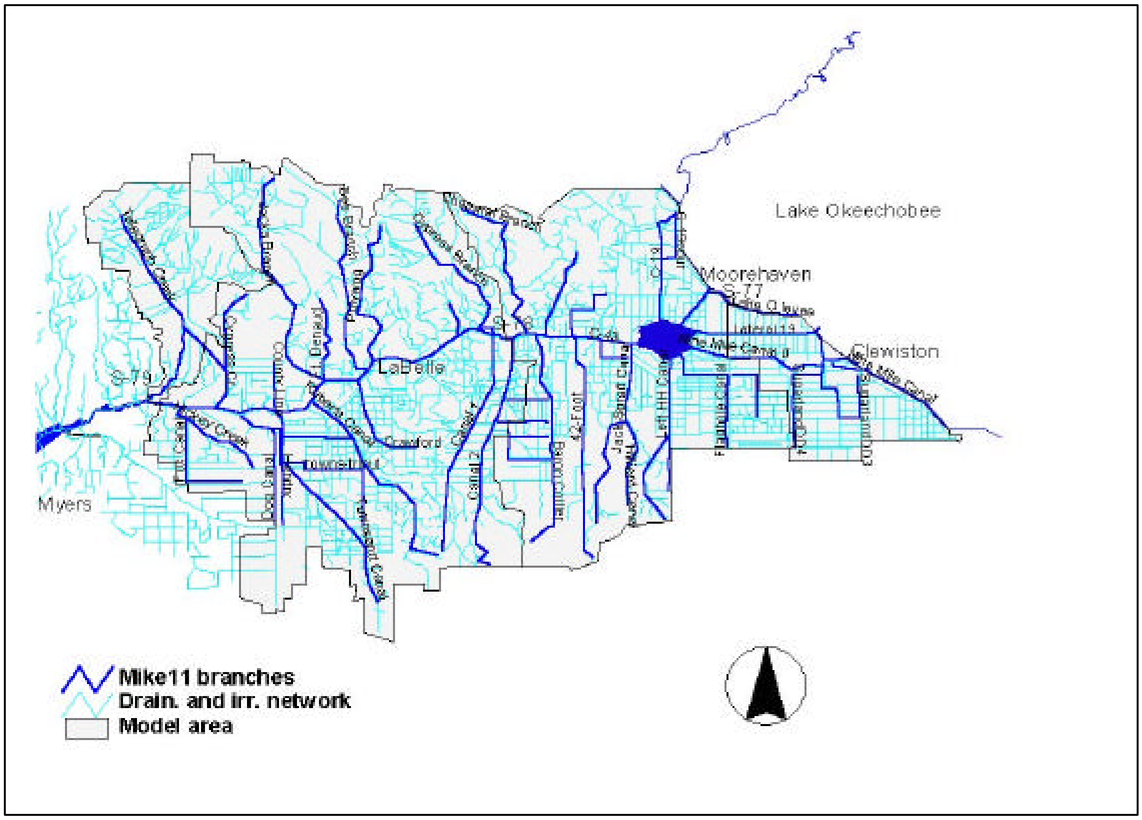

Figure 16 River and canal network represented in Caloosahatchee ISGM

A total of 47 branches are included as part of the river hydraulics model. The river network includes both irrigation and drainage canals. In the western part of the basin drainage is gravity driven, while drainage flow in the eastern part and pumps control irrigation supply in secondary canals.

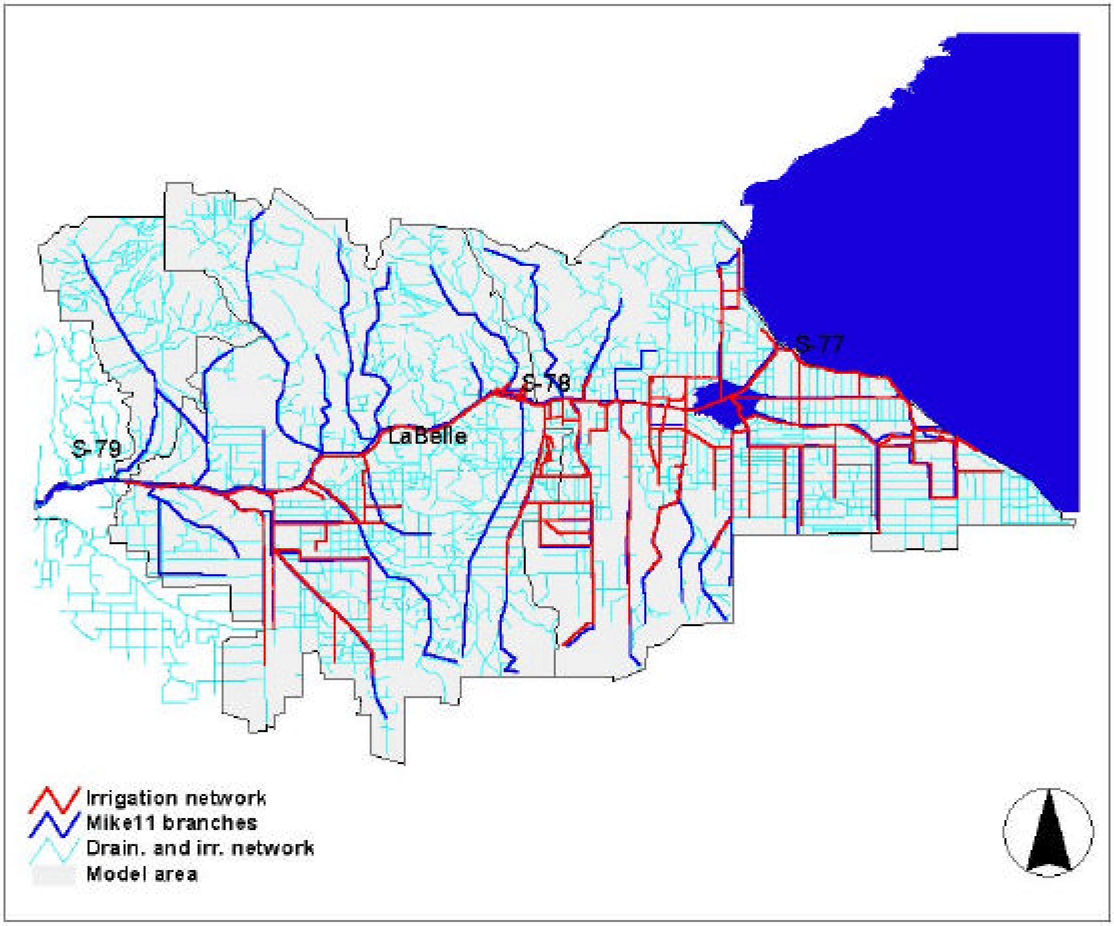

Figure 17 Irrigation network

2.6.2 Cross section data

The geometry of each river branch is specified in terms of cross sections. Cross sections and datum are important to both conveyance capacity and storage capacity at different reaches of the river system.

Cross-section data is generally scarce for most of the river network included in the model. Design data from construction of C-43 and a few major branches major canals exist at SFWMD. The available data cover a period from 1962-1992. Cross sections from parts of C-43, Jack's Branch, County Line Ditch, Canal 1, Canal 2, C-19, 42-foot canal and Hilliard Canal were provided by SFWMD from a number of reports. No up to date surveyed cross sections exist.

Due to the limited measured cross section data estimated cross sections have been entered from and overall assessment of canal dimensions. Trapezoidal cross sections have been assumed and canal bank elevation estimated from the topographical data.

Where cross section data have been available the cross section dimensions have been specified in accordance with design data e.g. C-43.

Table 11 Cross sections dimensions for canals represented in the river hydraulics model

Branch name	Width [feet (m)]	Depth [feet (m)]		Branch name	Width [feet (m)]	Depth [feet (m)]
C-43 Canal	164-367 (50-112)	16-26 (5-8)		Bee Branch	23 (7)	10 (3)
Hickey Creek	33-66 (10-20)	7-10 (2-3)		Polywog	33 (10)	13 (4)
Fox Canal	56-66 (17-20)	10-13 (3-4)		Dead Man's Br.	33 (10)	7 (2)
Dog Canal	56 (17)	10 (3)		Cypress Branch	39-46 (12-14)	1-13 (3-4)
Roberts Canal	16-108 (5-33)	3-10 (1-3)		Chaparal Branch	39 (12)	10-13 (3-4)
26-00082-W	43 (13)	10 (3)		22-00243-W1	23 (7)	10 (3)
Crawford	43-52 (13-16)	10 (3)		C-19	66 (20)	7-10 (2-3)
Canal 1	66 (20)	7-13 (2-4)		C-19spur	46 (14)	10 (3)
Canal 2	79 (24)	7-13 (2-4)		Townsend Canal	79 (24)	13 (4)
Baron Collier	180 (55)	16 (5)		Hendry	89-108 (27-33)	13 (4)
42-Foot	79 (24)	10-13 (3-4)		Telegraph Creek	33-66 (10-20)	7 (2)
Jack Spratt	66 (20)	7-10 (2-3)		Townsend Trib.	20 (6)	10 (3)
Hilliard Canal	66 (20)	7-10 (2-3)		Branch38	98 (30)	10 (3)
Left HH Canal	49-118 (15-36)	7-10 (2-3)		Branch39	98 (30)	10 (3)
Right HH Canal	49 (15)	7 (2)		Branch40	98 (30)	10 (3)
Flaghole	118 (36)	10 (3)		Branch41	98 (30)	10 (3)

Canal						
Nine Mile Canal	66 (20)	7 (2)		Jack Spratt X	26 (8)	10 (3)
Lateral 19	66 (20)	7-13 (2-4)		Flag Hole X	118 (36)	7 (2)
Lake Okee.levee	66 (20)	7-13 (2-4)		SugarlandDD4	118 (36)	7 (2)
Cypress Creek	23 (7)	10 (3)		S-310	66 (20)	7 (2)
County Line	33 (10)	10-13 (3-4)		Nine Mile Canal II	66 (20)	7 (2)
Jacks Branch	33 (10)	13 (4)		SugarlandDD3	118 (36)	7 (2)
Ft. Denaud	23 (7)	10-13 (3-4)				

1) The cross section widths refer to the main canal profile. Floodplains are not included.

2.6.3 Boundary conditions

Boundary conditions are specified at upstream and downstream ends of the river network. A constant flow boundary condition of 0.88 ft3/s (0.025 m3/s) has been applied to avoid numerical instability. The flow is not significant with respect to the water balance of the basin. The total flow introduced through the boundary conditions is less than 35 ft3/s (1.0 m3/s) or 0.47 inches/year (12 mm/year), which is negligible in terms of total water balance.

Time series of measured discharge from Lake Okeechobee (S-77) have been used as an upstream discharge boundary condition for C-43.

Measured time series of water levels downstream of Franklin Lock have been used as downstream boundary condition for C-43.

2.6.4 Hydraulic structures

The drainage and irrigation network is controlled by a large number of structures. In C-43 the combined weir/lock structures are operated partly for navigational purposes and partly to maintain acceptable water levels for irrigation. Many of the secondary branches are dug canals, which have been constructed to provide sufficient conveyance capacity for drainage, sufficient storage capacity for irrigation or both. To supply surface water to the upstream parts of the basin during dry periods the water is pumped upstream in from C-43 in stages separated by weirs or gates. Weirs are typically built in connection with pump stations. The pumps are activated when the water level upstream of the weir drops below the minimum acceptable level for irrigation. Water is diverted from the main secondary irrigation canals by pumps or by tertiary ditches and canals. During dry periods the pumps on the primary canals may run continuously to supply water to the upper reaches. The pumping rates are determined by irrigation demands and the availability of water in C-43.

All major hydraulic structures have been included as part of the MIKE11 model. Data for 28 weirs and 15 pumps has been incorporated in the river set-up. The majority of control structures are located in the southern part of the basin. Data for the hydraulic structures has been provided by SFWMD. In addition to the location of each hydraulic structure and the water permits they supply, required data include weir height, weir width, levels for pump operation, pump capacity, culvert dimensions.

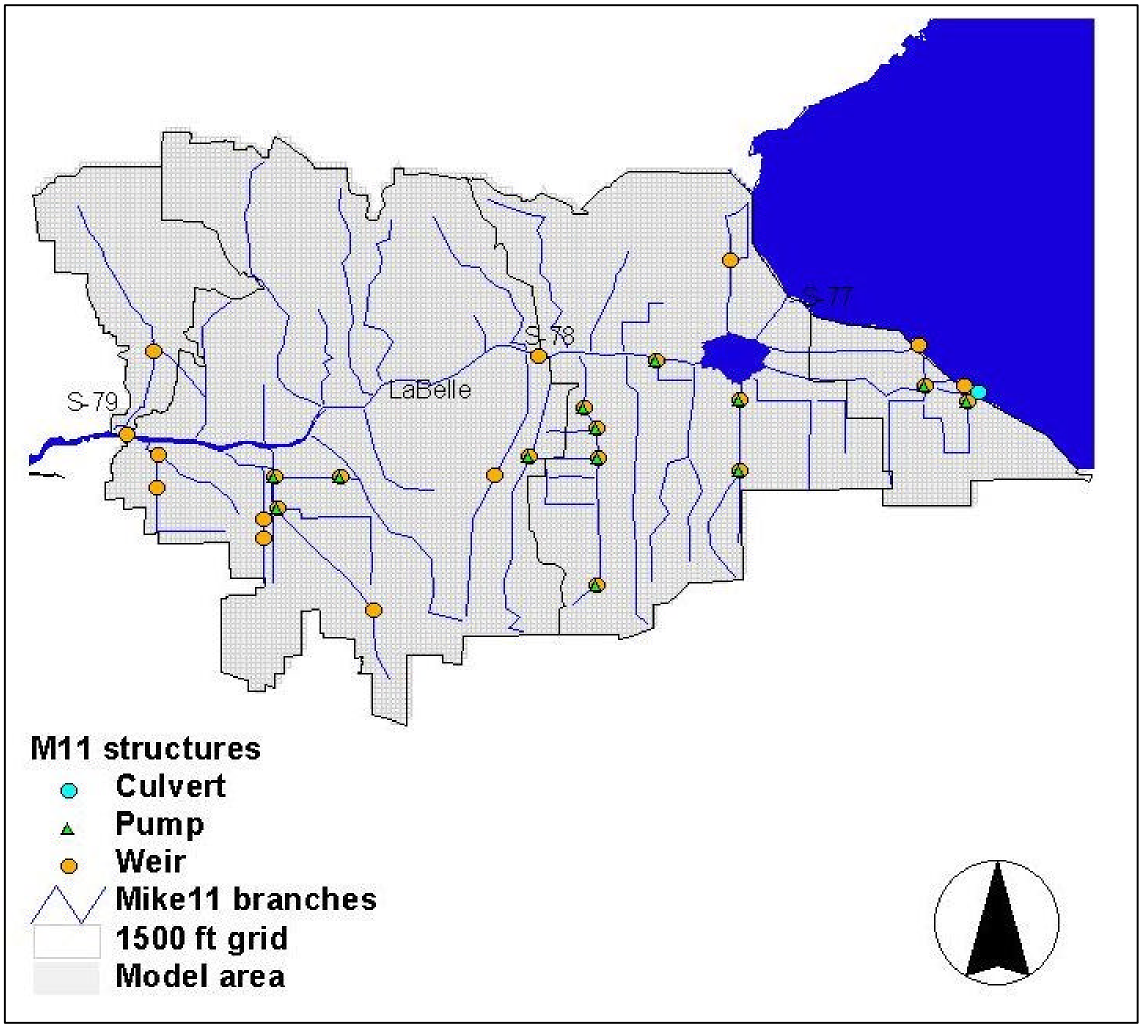

Figure 18 Surface water hydraulic structures in Caloosahatchee ISGM

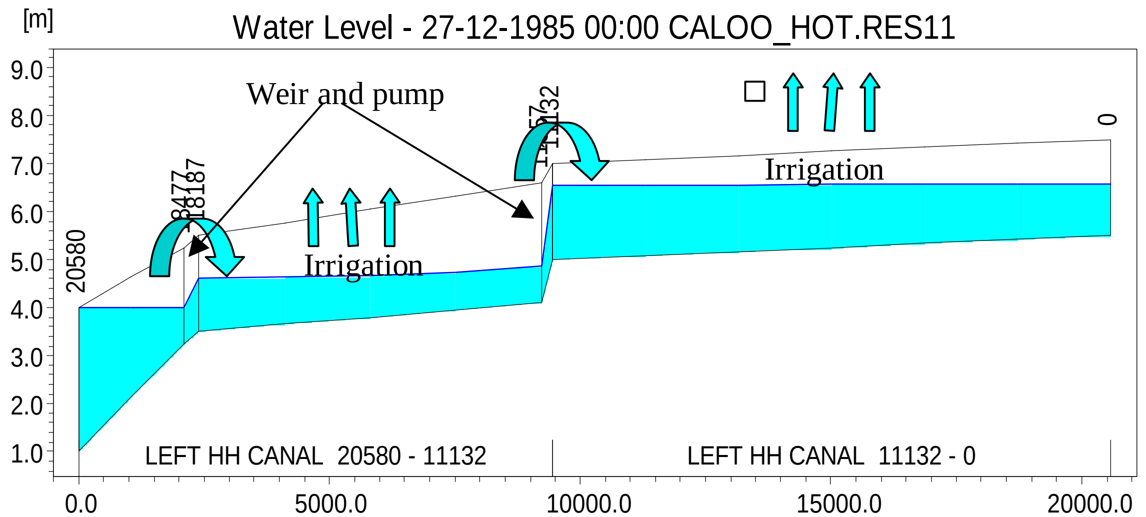

Figure 19 Example of combined weir and pump structure in MIKE11

2.6.5 Floodplains and inundated areas

The basin is generally flat with a number of flood plains or depressions (sloughs and swamps) adjacent to the river branches. At high water levels following rainfall events the river inundates the floodplain. When the river water levels recedes water accumulated on the floodplain drains back to the river. Dynamic floodplain simulation of the river/floodplain interaction is important in order to describe flow attenuation and surface water storage.

Lake Hicpochee and Telegraph Swamp are two major floodplain areas connected to C-43 and Telegraph Creek respectively. Their storage and conveyance capacity is represented by wide cross sections incorporating both main canal and floodplain features. The cross sections width increases with increasing water levels and flooding occurs as the water table rises above the bank level.

Flood plain data has been derived from the topographical model by comparing river bank elevations to the surrounding surface elevations. The 5-foot contour map may not represent the areas potentially flooded by riverbank overtopping in detail. The approximate retention volume of the low lying areas along the river branches assumed to be flooded is, however, sufficient to obtain flow attenuation and interaction between inundated areas and the sub-surface domain.

With emphasis on basin water balance simulations rather than detailed hydraulics and flooding the river model is sufficiently detailed at the coarser, regional scale.

Key calibration parameters for the MIKE11 simulation are Manning Bed resistance numbers and leakage coefficients for the exchange of water with the aquifer.

The Manning numbers applied in the MIKE11 model ranges from 20 to 50 $m^{1/3}/s$. From comparison of discharge time series at S-77, S-78 and S-79 it is seen that the delay in time and the reduction in peak flows in C-43 is very limited. Consequently, high Manning numbers have been applied in this part of the system. Both primary and secondary canals are generally kept free of vegetation.

The bed leakage coefficients are specified for each branch of the river system and describe the hydraulic contact between the river and the aquifer. The exchange of flow is described by a Darcy approximation as a function of the head gradient and the leakage coefficient. The hydraulic contact is relatively high except for parts of the system where organic matter and sedimentation of e.g. clays/silts reduces the conductivity alone the canal bed lining. A uniform value of 1e-6 s^{-1} has been applied for the entire river network. The leakage coefficient is likely to vary but the available data has not supported a distributed description.

2.6.6 Simulation

The computational time step applied in MIKE11 is 10 minutes. The time step has been chosen from the time scales and numerical constraints

2.7 Irrigation

The volume of water used for irrigation is important to the water budget of the Caloosahatchee basin. Agricultural development in the basin has lead to increasing irrigation water demands. During dry periods water is diverted from Lake Okeechobee to meet this demand. In order to assess the effects of possible future imposed restrictions on Lake Okeechobee water (Everglades restoration) in combination with further agricultural development in the basin a closer analysis of actual irrigation demands is required.

The purpose of simulating irrigation is to quantify demands and describe the effects of irrigation water allocation. The irrigation module (MIKE SHE IR) is applied in order to:

- Generate spatially and temporally varying irrigation demands depending on the simulated field conditions

- Simulate allocation of water from groundwater wells, irrigation canals or from sources outside the model area to meet the irrigation demand

- Simulate the effects on the basin water balance

Farmers irrigate to eliminate crop water stress and thereby avoid reductions in yield related to insufficient water supply. The feasibility of irrigating is, however, closely linked to costs for providing water and the plant response to water stress. Optimization of irrigation water supply in the field is often not possible due to lack of information on actual evapotranspiration rates. Soil water content could be used as an indicator but generally no unique criteria exist on irrigation practices with respect to timing of irrigation and the volumes applied. The management part of the irrigation depends on the operation of pumps and hydraulic structures at field level. On the larger scale little is known on the operation of structures at each field. Instead the irrigation module is applied focusing on the objectives of the irrigation i.e. to provide sufficient water for crop transpiration. The water resources in the water shed are to a large extent controlled to achieve optimal conditions for the crop.

2.7.1 Irrigated crops

A number of different crops in the basin are irrigated. Four major crops represented in the vegetation classification depends partially or entirely on irrigation. Sugar cane, citrus and truck crops (vegetables) must be irrigated as part of a profitable agricultural production. Improved pasture areas may also be irrigated in parts of the basin, but in the overall perspective it is assumed that pasture is not irrigated.

2.7.2 Irrigated areas

Two sources of information exist for describing which areas are to be considered irrigated. Landuse maps and SFWMD water permit coverages have been applied to produce a map of irrigated areas. Comparison reveals some discrepancies which introduces uncertainty on the total irrigated area. The bulk of irrigated land (approximately 90 %) can, however, be identified in both sets of data. The individual polygons of the derived GIS coverage has been applied to determine the extent of irrigated command areas i.e. areas being supplied from the same irrigation sources.

2.7.3 Irrigation demand

Little data exist to shed light on irrigation practices i.e. when farmers start irrigating and the actual supply rates and volumes. Field surveys in Caloosahatchee do not provide any operational rules, which could be assumed valid for the basin in general. The irrigation demand depends on many factors and is highly variable in time.

Calculation of irrigation demands relies on estimates of actual evapotranspiration. This approach is based on available meteorological data and aims at calculating the supplemental water required to maintain potential rates of evapotranspiration for the respective crops.

The use of an integrated hydrological model, simulating the water content in the root zone and the actual evapotranspiration rates, offers the opportunity of an alternative approach. By focusing on the purpose of irrigation rather than either describing fixed rates of supply or attempting to describe the actual operation of structures at field level, it is possible to formulate irrigation targets and determine the actual irrigation requirement to meet the targets.

In the MIKE SHE irrigation module the irrigation demand may either be given for each agricultural area prior to the simulation or it may be regulated from a set of management criteria. Some of the criteria are:

- Maximum allowable soil water deficit in the root zone
- Maximum allowable crop water stress (E_{act}/E_{pot})
- Prescribed time series of crop water requirements

The first option has been used for the Caloosahatchee model. In the vegetation database the targeted upper and lower limits of the average root zone soil water content of is specified as:

$$\Theta_{fc} - 0.1(\Theta_{fc} - \Theta_w) < \Theta < \Theta_{fc}$$

where Θ is the actual mean soil water content of the root zone, Θ_{fc} and Θ_w is soil water content at field capacity and wilting point respectively. The total soil water volume available for transpiration through plant uptake is (Θ_{fc} - Θ_w). Whenever the actual soil water content reduces below 90 % of this volume during the simulation the maximum allowable water deficit of the root zone is exceeded and irrigation water is supplied. The demand is calculated as (Θ_{fc} - Θ). If available the water is allocated at associated irrigation sources and supplied at the rate, (Θ_{fc} - Θ)/dtuz, in the following time step of the simulation. The allowable deficit is given relative to soil properties to account for the differences in soil properties in the model area.

The soil water content is kept close to field capacity to prevent any reduction in actual rates of evapotranspiration due to the soil water availability. To keep the soil water content within this narrow range irrigation water is supplied at a high frequency corresponding to an optimized operational schedule.

Using field capacity as the soil water reference level for irrigation is considered an appropriate approximation for citrus and truck crops, while the water table control used for irrigation in sugar cane fields may not fully

2.7.4 Irrigation water allocation

The water is supplied by conjunctive use of surface water and groundwater. The availability of surface water and groundwater varies in the basin. As a general rule the use of surface water is less costly than withdrawal of ground water. Ground water is mainly used in areas without irrigation canal network or when the surface water resource is scarce.

A link between irrigation command areas (fields) and specific locations for allocation of water is established by means of GIS pre-processing (Figure 22). Each irrigated area is associated with a prioritized list of river locations (defined by branch name and chainage) and/or groundwater wells from where the required irrigation water volume is allocated (if available). Limits are specified for each source in terms of a minimum river flow or groundwater potential head. At a given time the generated demand is met by, in order of priority, exhausting the available resource at the specified locations until sufficient water has been provided. If the total volume of available water does not cover the demand shortage occurs.

A general assumption has been adopted for the water allocation. First and second priority is given to nearby irrigation canals while third priority is given to shallow groundwater wells. Exceptions have been made in areas with no irrigation canals and a large density of irrigation groundwater wells and in the eastern part of the basin where water is pumped directly from Lake Okeechobee. The irrigation set up was modified by SFWMD based on water permit data. In a number of the irrigated areas individual wells were specified as the primary source of water.

The canal flow and storage may not be sufficient to meet irrigation demand in which case it for most areas would allocate water from the aquifer. Almost all canal cross sections and canal bed levels have been based on general assumptions on the canal dimensions due to lack of surveyed data and there is some uncertainty with respect to which irrigated areas are supplied from which points in the canals. Consequently the groundwater allocation may locally be overestimated if the available water in the canals is underestimated. As groundwater tables are reduced in response to irrigation withdrawals the head gradients and exchange between aquifer and canals is affected.

Irrigation set-ups have been developed for both 1988 and 1995 conditions.

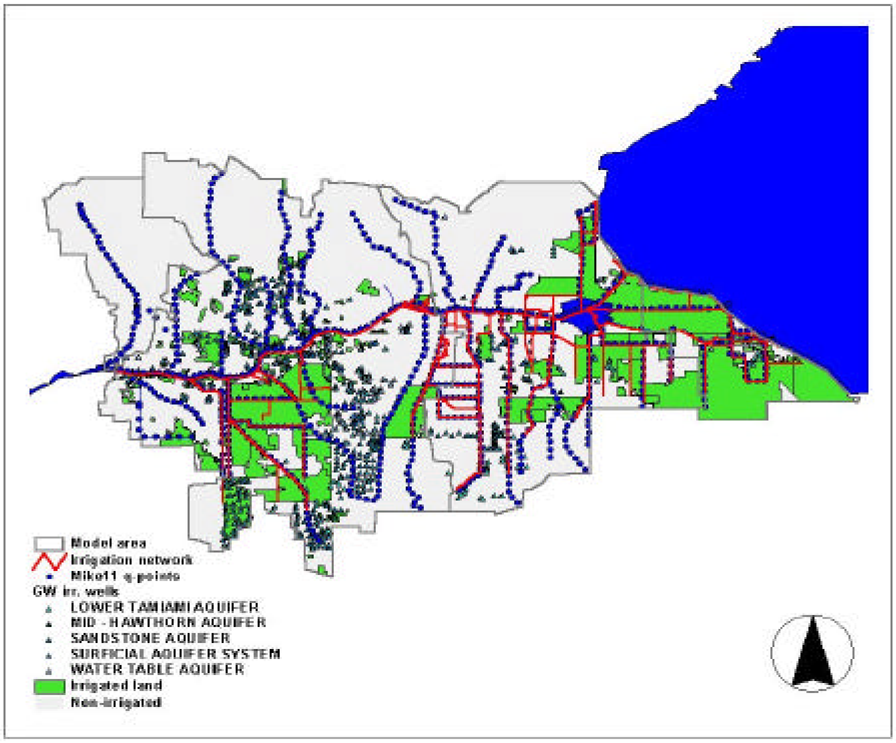

Figure 20 Irrigated areas and sources (1988)

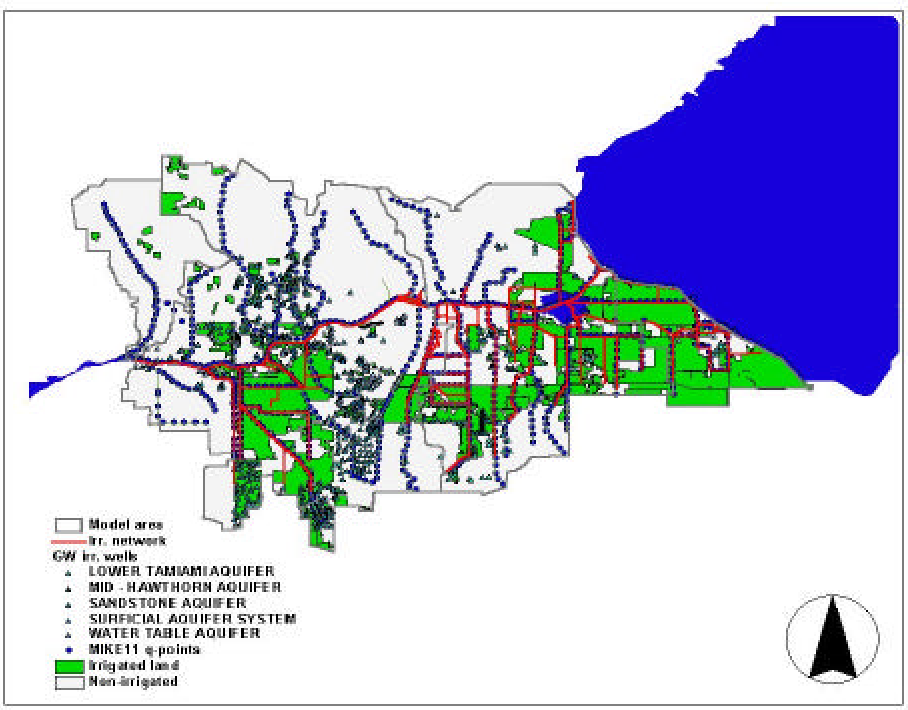

Figure 21 Irrigated areas and sources (1995)

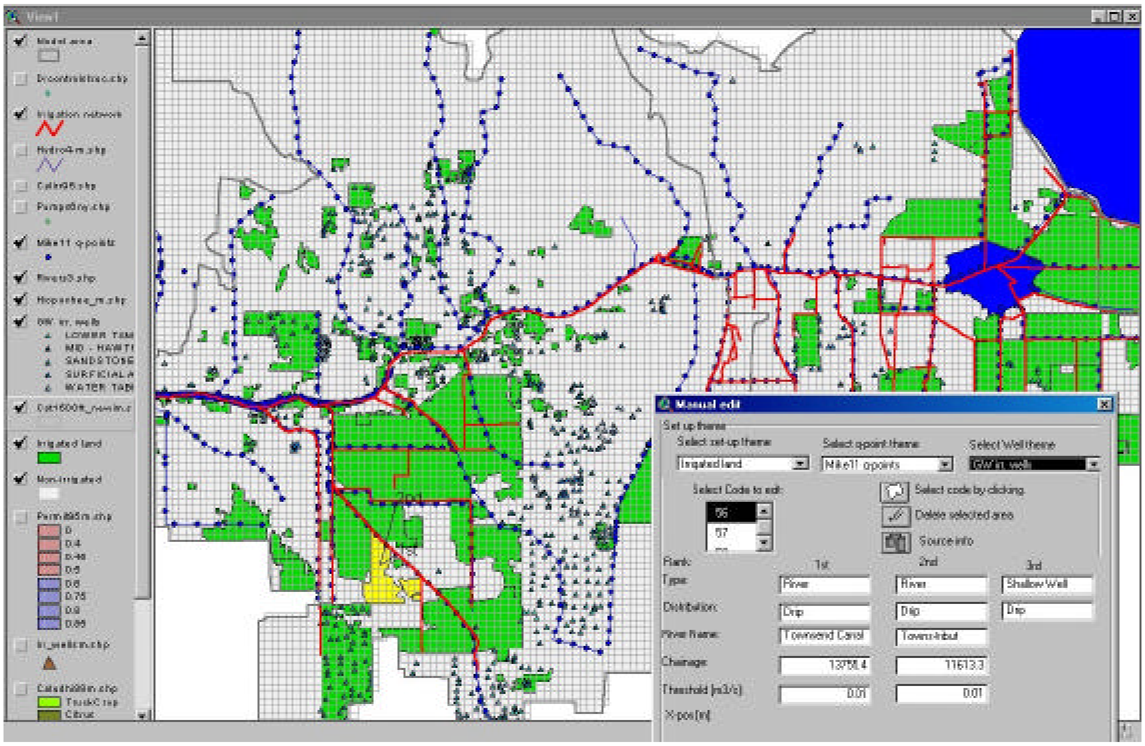

Figure 22 Water allocation - linking irrigated areas and sources through GIS

2.7.5 Irrigation water distribution method

Irrigation water may be distributed in the fields by means of different methods:

- Sheet flow - irrigation supplied at one location and distributed by local overland gradient (flooding)
- Sprinkler - irrigation added to rainfall
- Drip irrigation - irrigation supplied below the canopy avoiding interception losses

It must be stressed that the model terms used for distribution methods should be seen in relation to the grid scale applied in the model. For MIKE SHE and any other grid-based model the irrigation water is uniformly distributed to represent the average conditions of the area. Sub-scale variations are not represented and can only be dealt with by adopting finer grid resolution.

In the Caloosahatchee basin micro-irrigation is a widespread irrigation technique - especially in citrus groves. Micro jets are placed at the base of each tree wetting only the immediate surrounding area. Consequently, soil evaporation between rows is minimized. Sugar cane areas are typically irrigated by flooding or through water table control i.e. maintaining high water tables by increasing canal water stages. When water is pumped into the field the water is distributed depending on local surface slope. At the spatial scale applied in the model such local variation can not be described but must be described as the average of the area. The drip irrigation option has been used for the entire basin. An alternative may be considered to describe sugar cane areas in greater detail.

2.7.6 Irrigation efficiency and conveyance losses

To meet actual field demands water is allocated from irrigation canals or groundwater wells.

The efficiency of the irrigation scheme is always less than 1.0 implying that water is lost from the source to the point of application. In addition the water distributed in the field may not be available for crop transpiration due to a number of factors. If the supply rate exceeds the infiltration capacity of the soil water is lost due to overland flow or free surface evaporation, if the soil is already saturated or if water percolates below the root zone. If the soil becomes saturated when the groundwater tables rises there is no soil water deficit in the root zone and subsequently demand and supply equals zero.

Due to the relatively high conductivities of the soils in the Caloosahatchee basin and the frequent supply of irrigation water the infiltration capacity is rarely exceeded.

In each time step the irrigation water demand is approximately equal to the water lost from the root zone from evapotranspiration. The demand is calculated as the water deficit below field capacity i.e. the point where free drainage of the soil and infiltration to the groundwater occurs. On irrigated areas the percolation to the surficial aquifer is thus limited.

Canal conveyance losses are accounted for as canal-aquifer exchange along the river branches included in the MIKE 11 model (all primary canals) until the irrigation outtake points. Seepage from the canal system may occur if the head gradient is positive from the canal towards the aquifer. That does not change the demand but in response to significant conveyance losses a higher pumping rate from C-43 is required to maintain water levels in the irrigation canal. The water seeping into the aquifers will eventually reappear as a base flow contribution in the downstream part of the canal system.

3 MODEL CALIBRATION AND VALIDATION

The Caloosahatchee Basin Integrated Surface–Groundwater model covers the fresh water part of the Caloosahatchee basin. It is an integrated model including a suite of model components simulating the flow on overland and in river/canals, flow in the unsaturated and saturated zone, evapotranspiration losses to the atmosphere and an extension to describe the irrigation water use and its distribution.

MIKE SHE is based on a fully dynamic coupling between the different parts of the hydrological cycle. It is distributed implying that spatial and temporal variation within the model area is accounted for. MIKE SHE is characterized as distributed and physically based i.e. measured field data may be entered into the model and the model parameters have a clear physical interpretation.

The objective of the model development is to provide a modeling tool capable of assessing the impact of the extensive conjunctive use of groundwater and surface water on the total water balance. To be used for predicting effects of future management initiatives the model must be able to simulate historical records in the water shed.

The performance of the model depends on:

- Model conceptualization - the extent to which simplifications, assumptions and generalizations correspond to actual conditions
- Quantity and quality of basic input data - uncertainties associated with measured data
- Model parameters applied - the extent to which they apply for the model area and if they are supported by field data
- Accuracy, availability and distribution of field calibration references
- The numerical models ability to represent the flow processes

The calibration process is primarily aiming at obtaining a set of model parameters, which provide a satisfactory agreement between model results and field observations. The definition of 'satisfactory' is not clear, hence more objective criteria should be introduced bearing in mind the purpose of the model. Choosing objective criteria which ensures an accurate calibration is, however not trivial. Emphasis must be put on variables with pronounced effect on the water balance. The Caloosahatchee model is calibrated for the period 1986-1990 - a period chosen in order to represent both dry and wet conditions

The model validation serves to verify that the deviation between observed and simulated values within the calibration period also applies to an independent time period. The period 1994-1998 was selected for validation

Upon calibration and validation of the model a sensitivity analysis may be carried out to test how the model responds to variation of certain parameters or input data. Key parameters having a significant effect on model results may be identified and their effect on model uncertainty assessed.

The model is calibrated against available time series of observed canal discharges and groundwater heads. A wide range of outputs can be derived from the model and apart from objective statistical based criteria the model must be evaluated through the overall capability of representing common hydrological and physical features of the basin i.e. flood duration, flood extent, irrigation water demand etc.

It is important to stress the non-uniqueness of the final set of parameters obtained from the calibration process. The number of parameters and their possible combinations is high. Field data are used to limit the range of model parameters and thereby reduce the number of possible outcomes. Even by imposing restrictions supported by field data several sets of parameters may yield an acceptable calibration. Consequently the parameter combination used should be seen as one likely alternative.

3.1 Input data and model parameters

The input data requirements and model parameters for the fully integrated MIKE SHE model are comprehensive. Each component of the model applies a range of input data types and parameters. The parameters may be physically measurable or empirical specific to the equations solved in the model.

Table 12 List of model input and parameters for MIKE SHE

Model component	Model Input	Model parameters
MIKE SHE SZ Saturated zone flow	Geological model (lithological information Boundary conditions Drainage depth (drain maps) Wells and withdrawal rate	$K_{h,}$ Horizontal hydraulic conductivity $K_{v,}$ Vertical hydraulic conductivity S, confined storage coefficient S , unconfined storage coefficient Drainage time constant
MIKE SHE UZ Unsaturated zone flow	Map of characteristic soil types Hydraulic Conductivity Curves Retention curves	Ks, saturated hydraulic conductivity Θs Saturated water content Θ_{res} Residual water content Θ_{eff} Effective saturation water content pFc, Capillary pressure at field capacity pFw, Capillary pressure at wilting point n, Exponent of hydraulic conductivity curve
MIKE SHE ET Evapotranspiration	Time series of vegetation Leaf Area Index Time series of vegetation root depth	C_1, C_2, C_3 : Empirical parameters C_{int} : Interception parameter A_{root} :Root mass parameter Kc : Crop coefficient

MIKE SHE OC Overland and river/canal flow (MIKE11)	Topographical map Boundary conditions Digitized river/canal network River/canal cross sections	M, Overland Manning no. D , Detention storage L, leakage coefficient M, River/canal Manning no.
MIKE SHE IRR Irrigation module	Irrigated areas Irr. sources (pumps/canals/reser voirs) Distribution method (sheet, sprinkler, drip) Source capacity	Eact/Epot, crop water stress factor (target ratio between actual and potential evapotranspiration rates)

The conjunctive use of surface water and groundwater requires a resource assessment including both surface and sub-surface domains. The calibration has consequently been aimed at obtaining a satisfactory agreement for both C-43 discharge and observed groundwater heads in the shallow and deep aquifers.

The canals are the primary source of irrigation water and in the calibration process first priority has been given to simulating the dry period canal flow, secondly to obtain the approximate storm peak discharges and total accumulated runoff. The lateral contributions to river flow are overland flow, seepage between aquifer-canals and drainage flow. The storm discharge is dominated by overland and drainage flow contributions. Given the limited surface slope and the relatively high infiltration capacity of the soil overland sheet flow only add to the canal flow during high intensity storms. The groundwater drainage and interflow is thus important to the rising leg and recession of the simulated hydrograph. Consequently the calibration of surface water has focused on the drainage response. The drainage depth and drainage time constant of areas considered drained has been subject to changes. The drainage depth has been varied between 1.6 - 4.1 feet (0.5-1.25 m). Increasing the drainage depth will effectively increase the volume of groundwater discharged into the canals and thus the downstream peak flows. The drainage level does, however, also affect

The drainage water level has been compared to root depths of the vegetation. In cropped areas the drainage level is controlled to avoid longer-term water logging that potentiallt could cause damages to the crop. On the other hand the root mass distribution may reflect the actual depth to the groundwater table i.e. development of deeper roots secures the water uptake during droughts. In general the drainage level should effectively drain the ground water when the root zone is completely or partly saturated. On the other hand the plant water uptake of water in the dry periods may reduce the water tables significantly below the drainage level. If significant drainage flow persists during dry periods it may be seen as an indication of too low drainage levels. As only scarce information exists for describing the distributed drainage levels, it has been treated as a calibration parameter.

Other calibration parameters include conductivities and storage of the aquifers, saturated hydraulic conductivity of the unsaturated soils, aquifer-canal leakage coefficients and Manning numbers of the river/canal. The effect of changing root depth and leaf area index was also investigated

The simulated low flow is a function of surface water diversion at S-77, storage in the canals, the aquifer base flow and the irrigation water outtake from the canals. Applying small leakage coefficients reduce the aquifer base flow and adjusting drainage levels to minimize dry period drainage flow. The crop parameters affecting actual evapotranspiration and corresponding irrigation demand were tested by changing the root depth 1.6 - 4.9 ft. (0.5-1.5 m). The rooting depth was not found to change the total demand significantly in irrigated areas. The leaf area index (1.0-6.0) is generally not limiting the actual evapotranspiration.

3.2 Calibration

To test whether the selected set of model parameters applies to both dry and wet conditions the model is calibrated for a period with both dry and wet years (1986-1990).

Field measurements constitute the primary calibration references. In the Caloosahatchee model river/canal discharges and groundwater levels are used to calibrate the model. The time series of observed potential heads have been collected as part of previous ground water flow studies for Lee, Hendry and Glades County. They have been assigned to the deep and shallow aquifers respectively (water table aquifer and sandstone aquifer) from well screen information. All of the available observation wells are located in the southern part of the model area. 12 shallow wells and 12 deep wells are found inside the model area south of Caloosahatchee River (C-43). Calibration of groundwater heads is not possible in the remaining part of the model area due to lack of data.

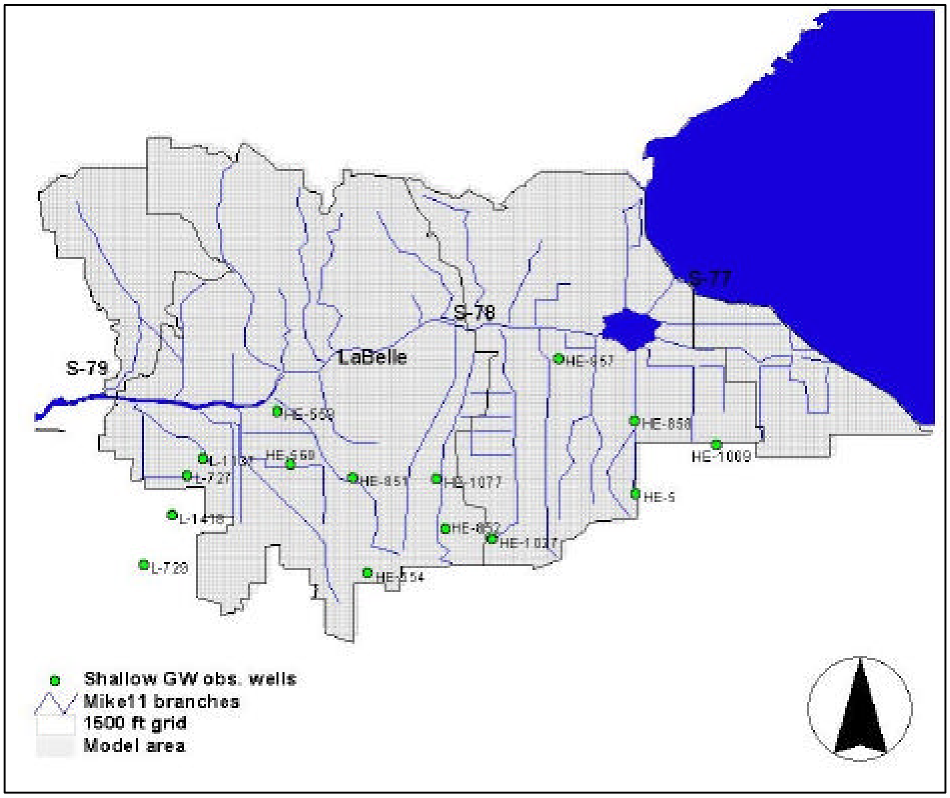

Figure 23 Observation wells, shallow aquifer

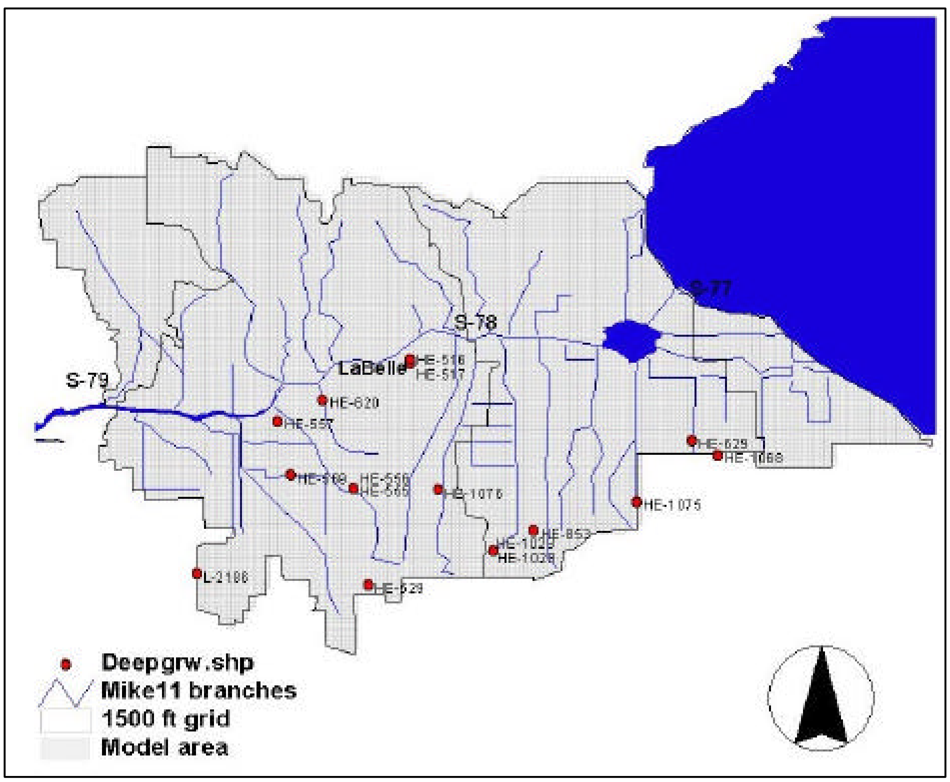

Figure 24 Observation wells, deep aquifer

Discharges have been recorded at the Caloosahatchee canal at Moorehaven, Ortona and Franklin lock (S-77, S-78 and S-79). Moreover discharges have been measured at Canal 19 at S-342, S-47b and S-47d for a shorter period. The time series of flow at S-78 includes the total run-off from the eastern part of the basin.

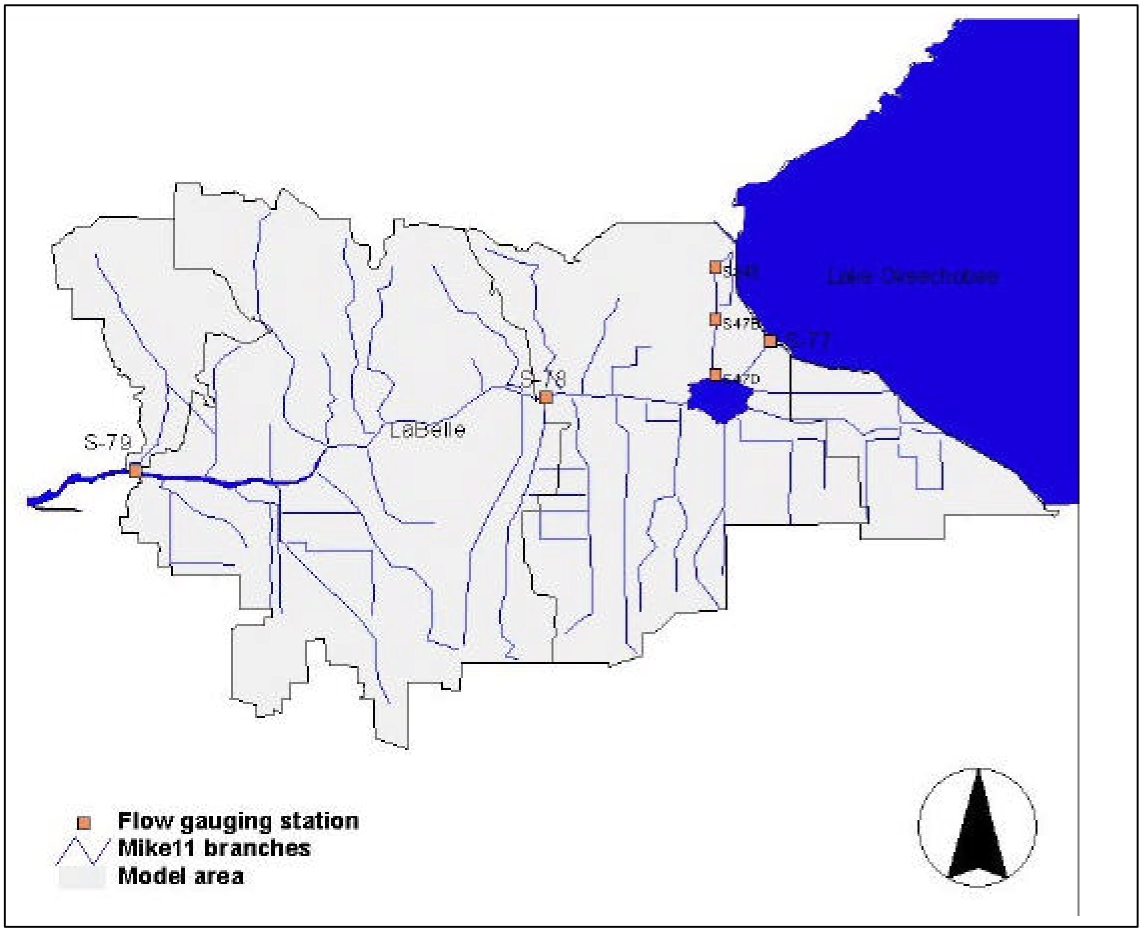

Figure25 Surface flow-gauging stations

Apart from field measurements the model may be evaluated from a more general view. The ‘soft’ calibration references could include:

- Aerial photos of flooding.
- Irrigation water demand
- Water balance
- Flow dynamics and general physical characterstics

The model results are evaluated from the general knowledge and understanding of the model area. As no ‘hard’ data in terms of measurements exist the comparison between simulations and the field conditions is qualitative implying the overall pattern and performance of the hydrological system is verified against the common conception of the basin hydrology.

The first phase of the Caloosahatchee Basin Integrated Surface –Groundwater model aims at establishing a regional model for the freshwater part of the basin in a 1500 ft computational grid. It is thus only possible to compare model results with field conditions on the coarser scale. Hence, the lumped nature of model input and parameters on to a 1500-ft grid does not support interpretation on a detailed sub-scale level. By decreasing the grid scale in a local model it is, however, possible to analyze the model results in further detail. Development of detailed models is not within the scope of the present study.

3.3 Calibration Targets

The definition of a satisfactory calibration is not very clear and depends on the purpose of the model. Various criteria may be adopted to quantify the maximum tolerable deviation between observations and simulations. When comparing time series statistical measures of fit between the simulated and observed variables may be introduced. It is, however, difficult to provide predefined calibration targets tailored for the specific purpose of the Caloosahatchee model. In terms of water balance the ability of the model to simulate both wet and dry period conditions is required. On the other hand water resource problems in the basin are only seen during dry period with high irrigation demands implying that low flows periods should be subject to special attention. The formulated calibration targets have been based on general criteria and they have not been tailored to the specific purpose of the Caloosahatchee basin model or the availability of field data. Subsequently, they should be seen as overall guidelines.

For the ground water component of MIKE SHE it is the objective first of all to simulate average ground water potential head within the simulation period. Secondly the range of potential head (maximum and minimum levels) should be represented. Finally the model, to the extent possible, should describe the full dynamics given limitations in input data.

During the project "Developing a Small Scale Integrated Surface Water and Groundwater Model for the South Florida Hydrogeologic System"carried out for the South Florida Water Management District by Danish Hydraulic Institute a set of improved model calibration utilities were developed. The utility calculates statistical criteria for the deviation between observed and simulated time series of potential head at each observation well:

- $R1_j$:

Percentage of time where the absolute value of ($RES_{i,j}$ - $RES_{std,j}$) is less than 25% of ($H_{obs,max,j}$ - $H_{obs,min,j}$)

- $R2_j$:

Percentage of time where $H_{sim,i,j}$ lies within the range ($H_{obs,i,j}$ - $H_{obs,std,j}$; $H_{obs,i,j}$ + $H_{obs,std,j}$)

- $R3_j$:

Percentage of time where $H_{sim,i,j}$ lies within the range ($H_{obs,min,j}$; $H_{obs,max,j}$)

- $R4_j$:

Percentage of time where $H_{sim,i,j}$ lies within the range ($H_{obs,i,j}$ - 1 foot ; $H_{obs,i,j}$ + 1 foot)

where

N_{time} : number of observed values in a time series ($i = 1,N_{time}$)

N_{wells} : number of observation wells ($j = 1,N_{wells}$)

$H_{obs,min,j,}$ $H_{obs,max,j,}H_{obs,std,j}$: Minimum, maximum and standard deviation of observation time series

$RES_{i,j}$: Residual ($H_{obs,i,j}$ - $H_{sim,i,j}$)

$RES_{std,j}$: Standard deviation on residuals

The R1, R2, R3 and R4 criteria are not universally valid statistical criteria, which will ensure a satisfactory calibration in any model set up. The do, however, represent objective numerical criteria which may be indicative of calibration accuracy in general.

The above listed criteria are applicable to the calibration of groundwater tables. For the surface water discharges a close agreement between measured and simulated flow should be obtained in terms of dry period flows, peak flows and accumulated run off. The following targets were suggested for the river flows:

Table 13 Suggested calibration targets for C-43 discharge

Calibration Criteria			
	Cumulative Mass error	Std. Dev. of the error	Avg. cumulative mass error
West Basin Deficit	5 %	5 days 20%	5%
		30 days 10%	
West Basin Excess	5 %	5 days 35%	5%
		30 days 15%	
East Basin Deficit	5 %	5 days 20%	5%
		30 days 10%	
West Basin Excess	5%	5 days 35%	5%
		30 days 15%	

Peak flows in C-43 may not be fully captured by the model due to the high variability in rainfall during storms compared to the density of rainfall stations and the uncertainty of readings during storms. In terms of water balance and water shortage it is more important that the model simulates the recession in flows following discharges of large volumes of storm water and the intermediate dry periods. Dry period flows are influenced by the irrigation water demands and the control structures operated to distribute the water. Consequently the simulated dry period flow is indicative of the balance between canal storage, canal flow contributions (groundwater seepage and drainage) and irrigation diversions based on simulated water demands. Short-term fluctuations in measured discharge time series (daily) are attributed to operation of locks and other hydraulic control structures. Due to the limited information on actual structure regulation and the exact operational schedule the model can not represent such fluctuations. Subsequently it is the objective to simulate low flow as the average minimum flow within each dry period.

The requirement to simulate the accumulated flow in the main canal serves to ensure a correct water budget for the eastern (S-78) and the western (S-79) part of the basin. Accumulated flows are evaluated for the entire simulation period.

3.4 Primary Calibration Parameters

The hydrological regime and thus the water balance of the Caloosahatchee basin is characterized by relatively high rates of rainfall (approximately 60 inches/year (1500 mm/year)) and evapotranspiration (pan evaporation of approximately 79 inches/year (2000 mm/year)). The evapotranspiration is the dominant factor of the water budget with or without irrigation. The infiltration capacity of the soils is high and the net rainfall recharges the water table aquifer. The flow in the water table aquifer is in general directed towards the numerous canals and ditches. Due to partly the hydraulic contact between surface water bodies and the upper aquifer sequence and partly the dense drainage networks the shallow groundwater seeps into the canals.

The number of parameters and possible combinations is large for distributed models. It is thus imperative to restrict the parameters subject to modification during the calibration and to the extent possible define ranges of the individual parameters applied to obtain a successful calibration. Within each model component the primary parameters must be specified and parameter intervals (minimum and maximum values) specified from measured field data, general characteristics of the model area and experience

.

Table 14 Primary parameters adjusted during calibration

Model component	Calibration parameters	Parameter range
MIKE SHE SZ – Saturated zone flow	K_h: Horizontal hydraulic conductivity K_v: Vertical hydraulic conductivity Drainage time constant	Determined from pump test transmissivity data $0.01 < K_v/K_h < 1.0$ 0.00001 - 0.001 s^{-1}
MIKE SHE UZ – Unsaturated zone flow	pF_{fc} Capillary pressure at field capacity n, Exponent of hydraulic conductivity curve	$1.0 < pF_{fc} < 2.0$ $5.0 < n < 20.0$
MIKE SHE ET – Evapotranspiration	Aroot : Root mass parameter K_c : Crop coefficient	0.8-1.2 0.7-1.2
MIKE SHE OC – Overland and river/canal flow (MIKE11)	M, Overland Manning no. D , Detention storage L, leakage coefficient M, River/canal Manning no.	1-10 m1/3/s 0.03 ft (0.01 m) 1e-3 – 1e-7 s-1 20-30 m1/3/s
MIKE SHE IRR – Irrigation module	Eact/Epot, crop water stress factor (target ratio between actual and potential evapotranspiration rates)	0.90 - 1.00

3.5 Calibration results

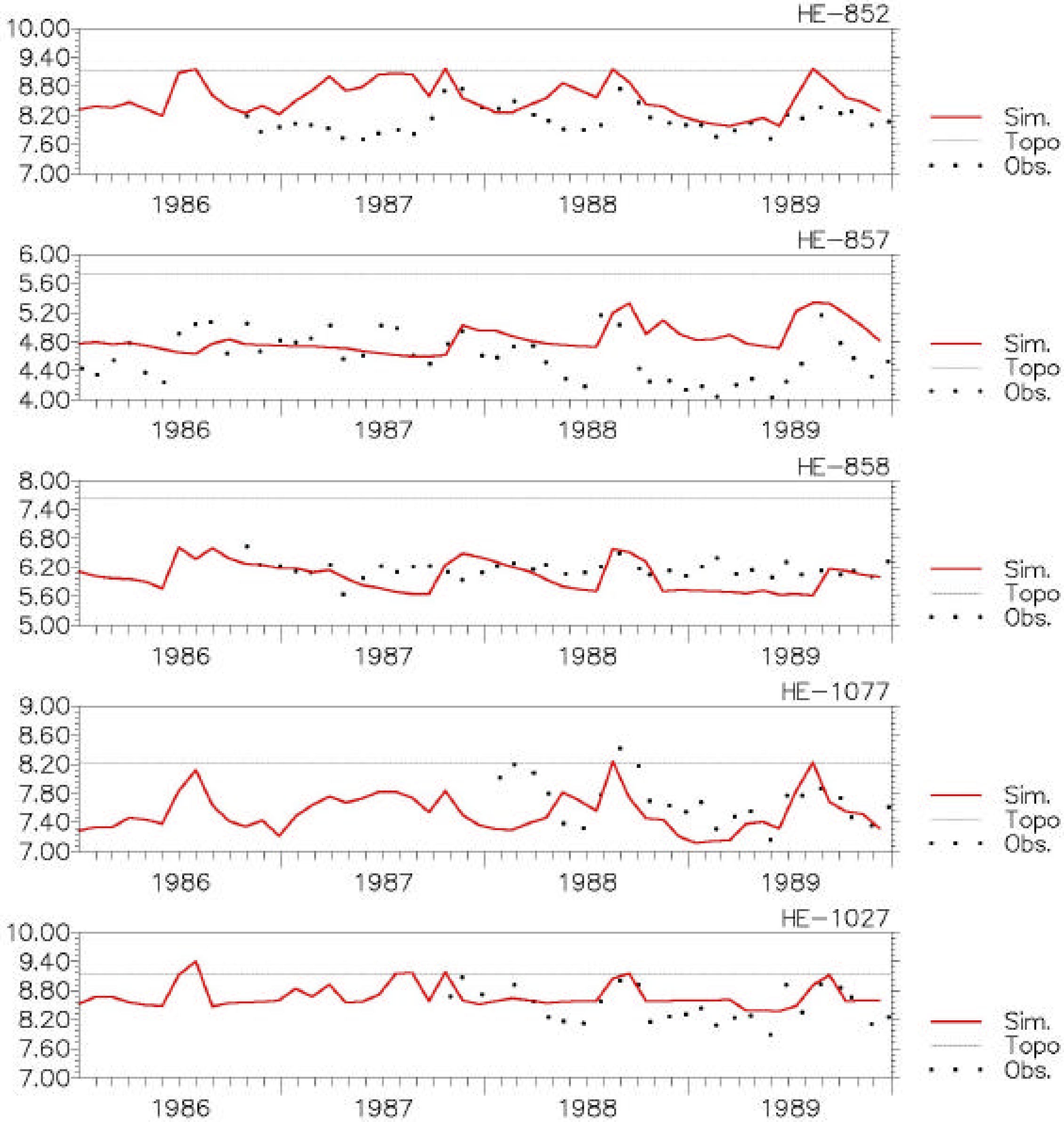

Figure 26 Simulated and observed potential head in shallow aquifer (m), 1986-1990 (I)

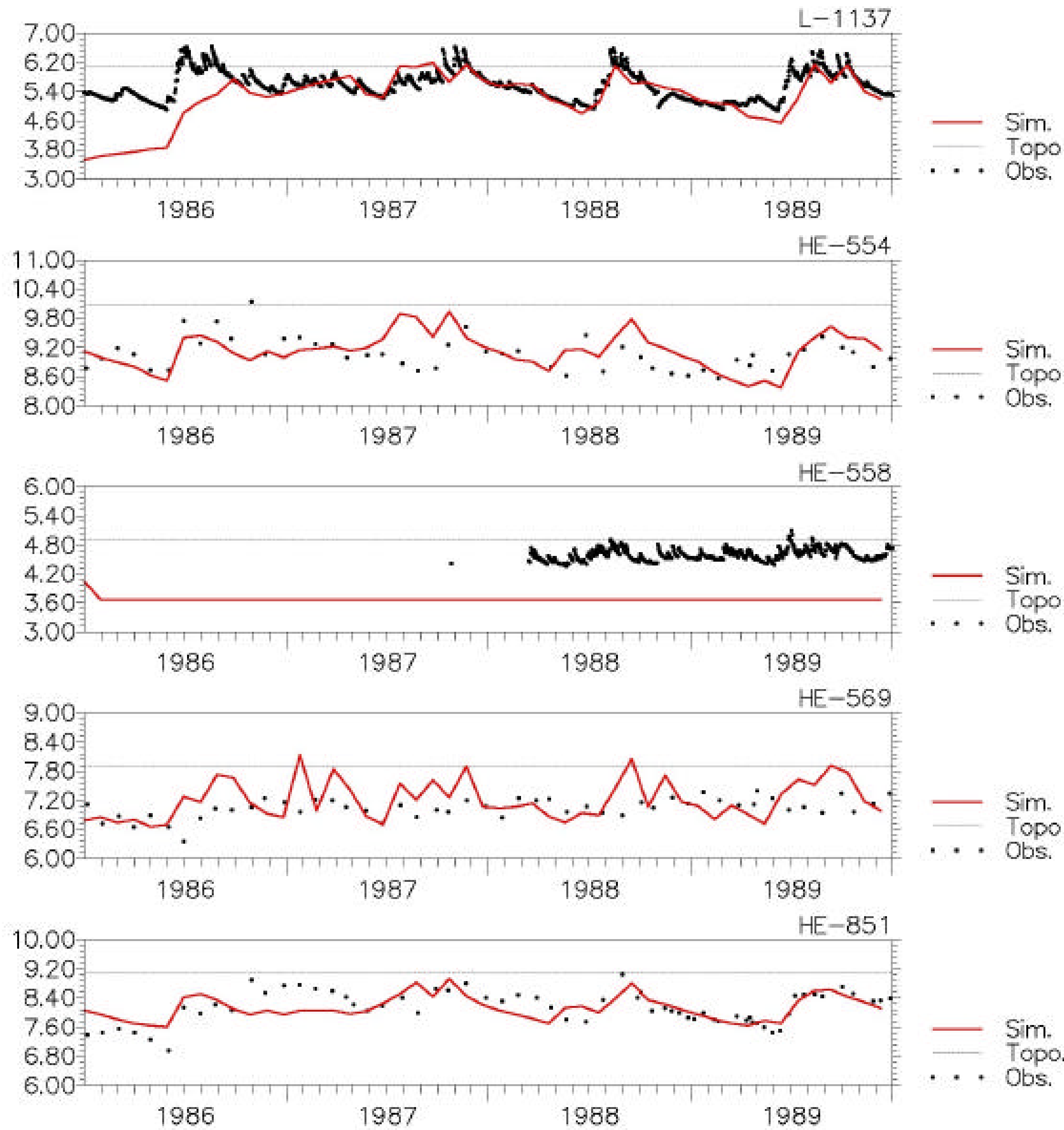

Figure 27 Simulated and observed potential head in shallow aquifer (m), 1986-1990 (II)

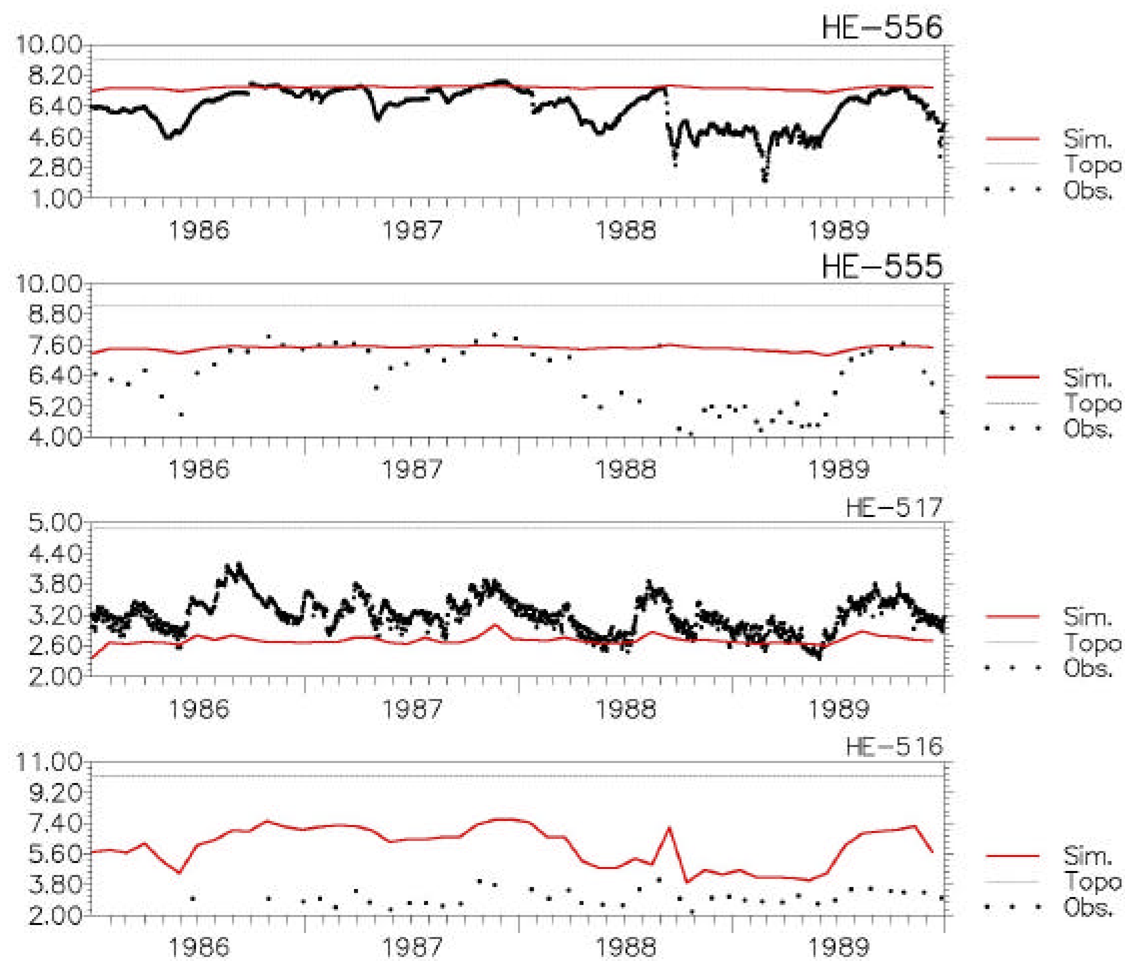

Figure 28 Simulated and observed potential head in deep aquifer (m), 1986-1990, (I)

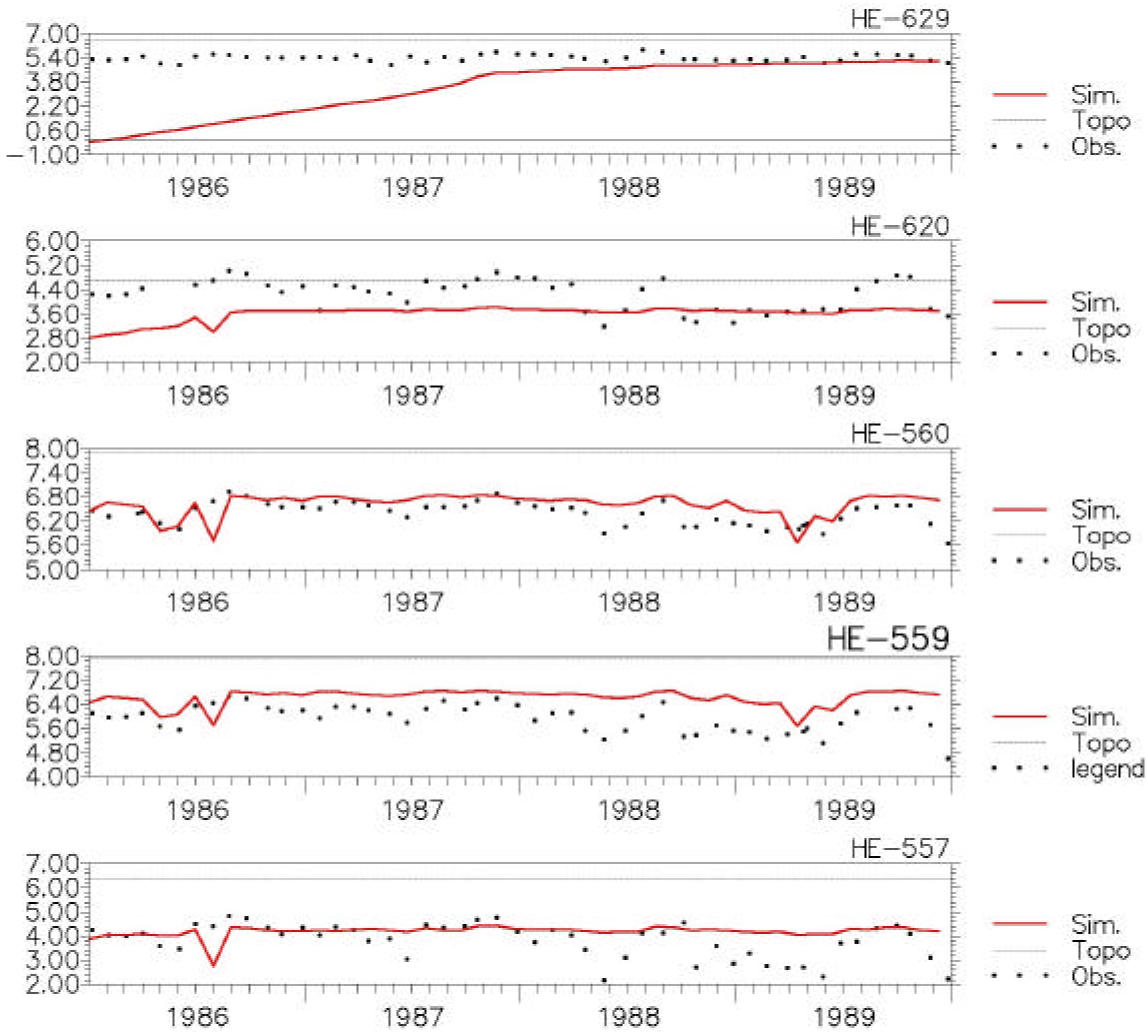

Figure 29 Simulated and observed potential head in deep aquifer (m), 1986-1990, (II)

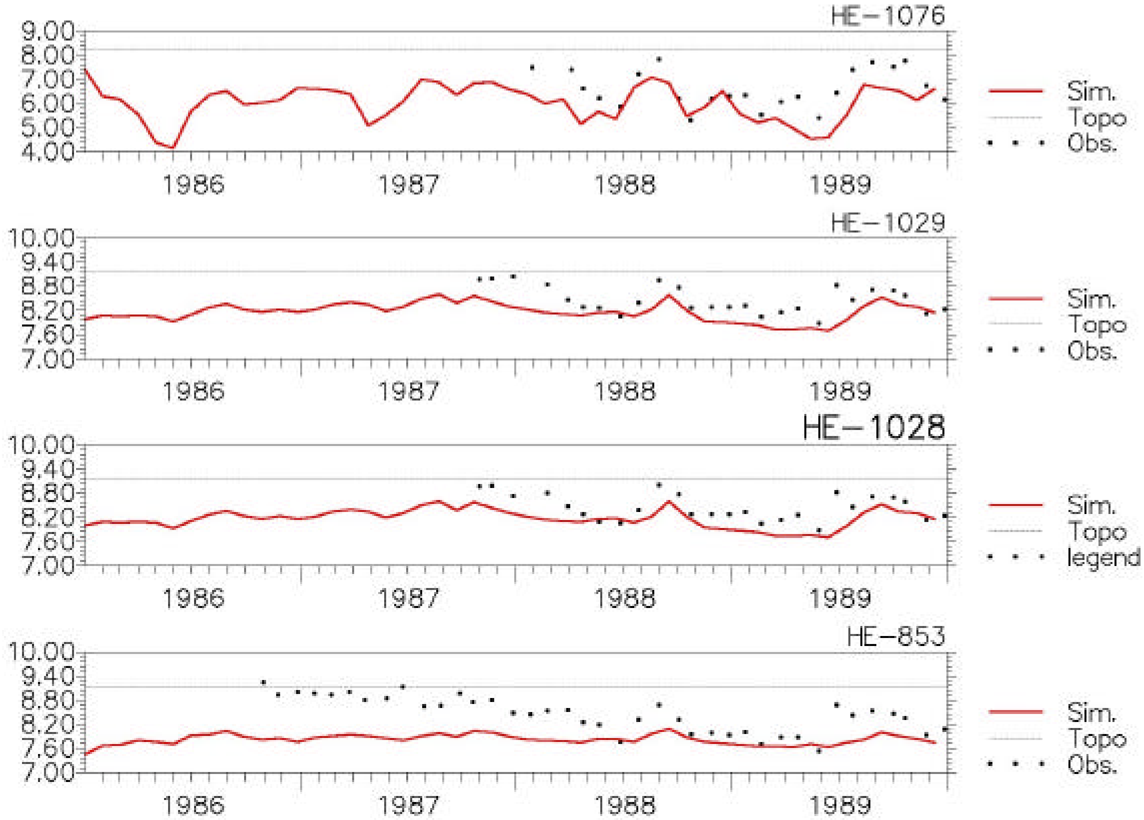

Figure 30 Simulated and observed potential head in deep aquifer (m), 1986-1990, (III)

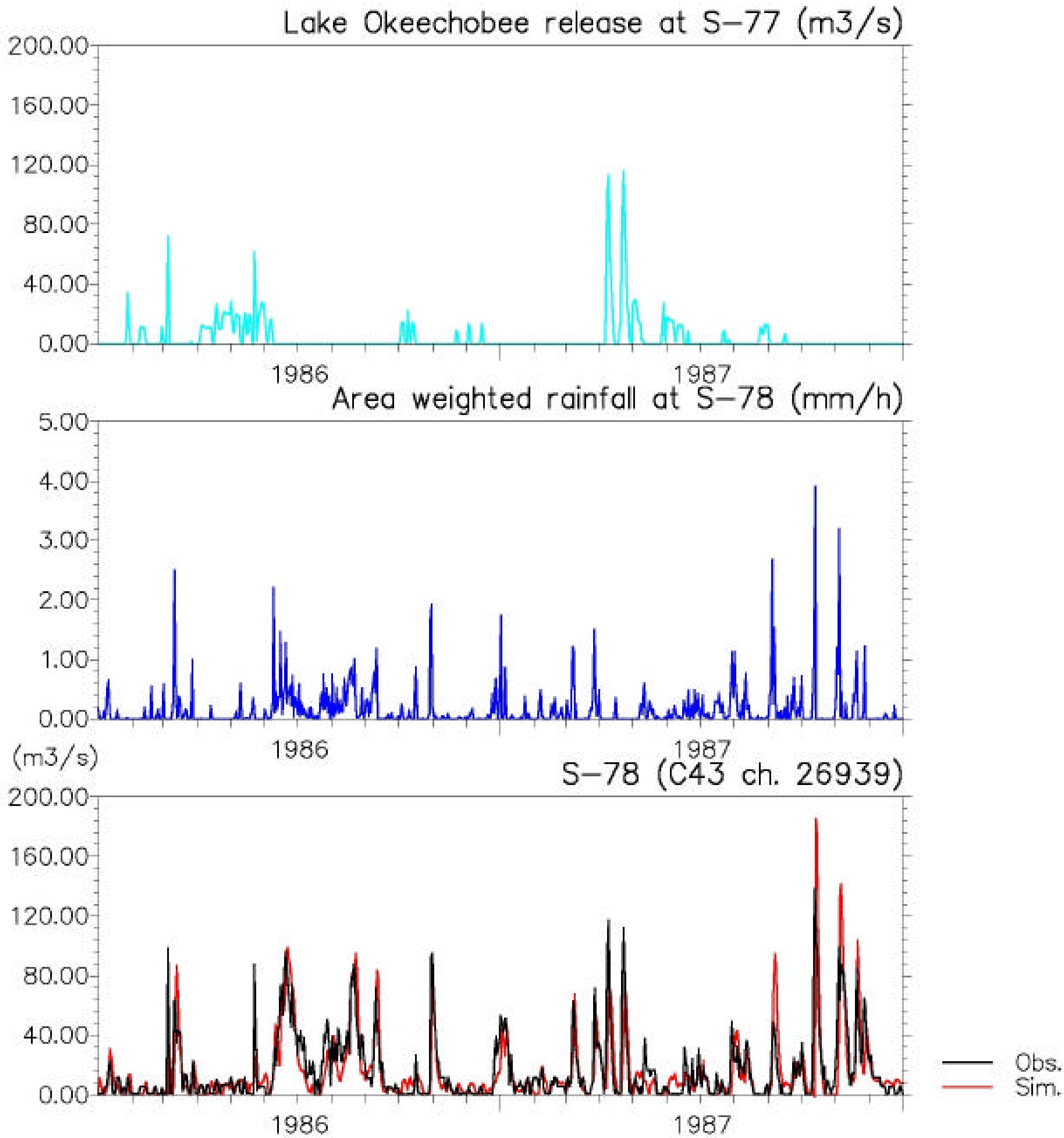

Figure 31 Simulated and observed canal flow (S-78), 1986-1988

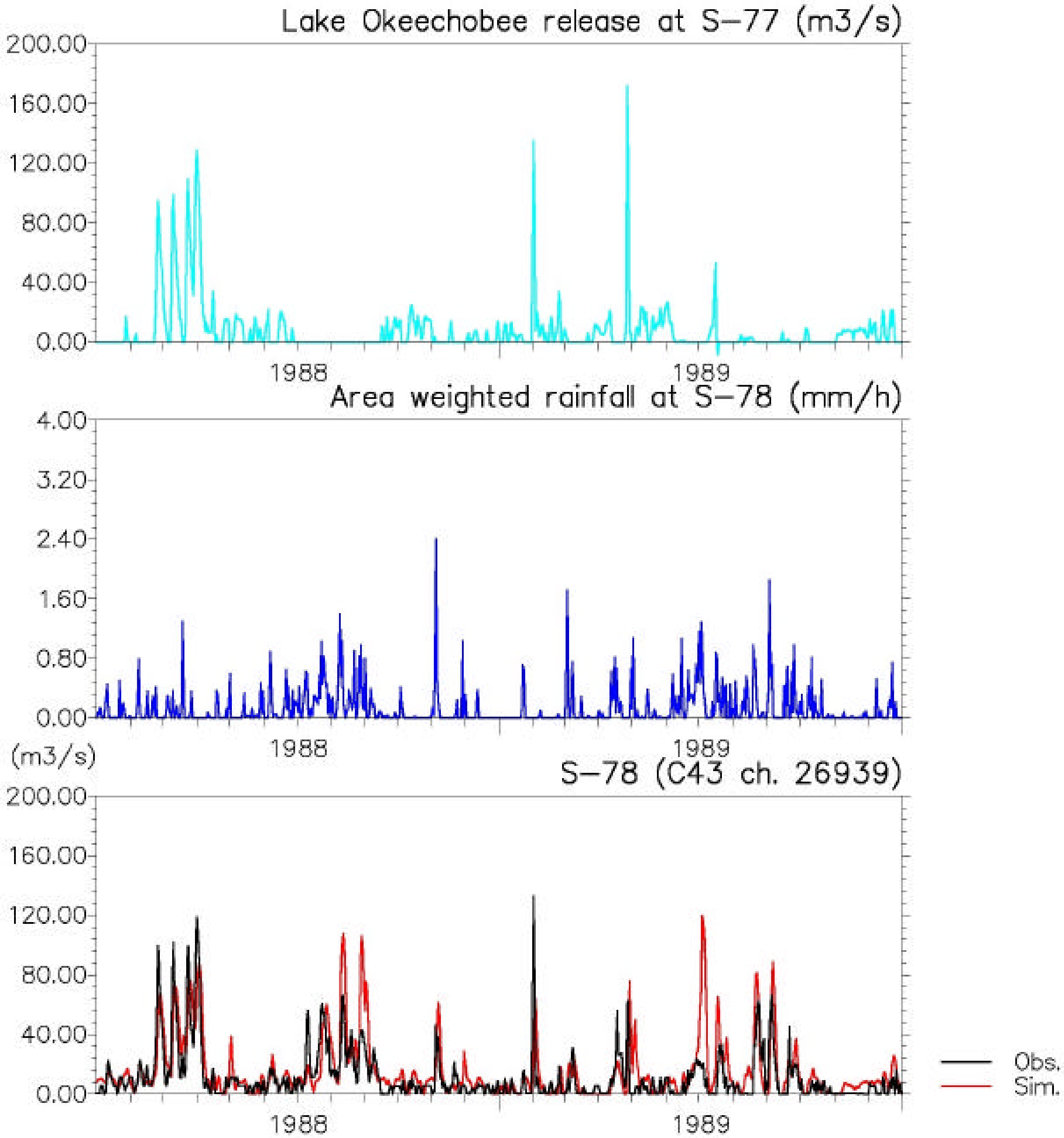

Figure 32 Simulated and observed canal flow (S-78), 1988-1990

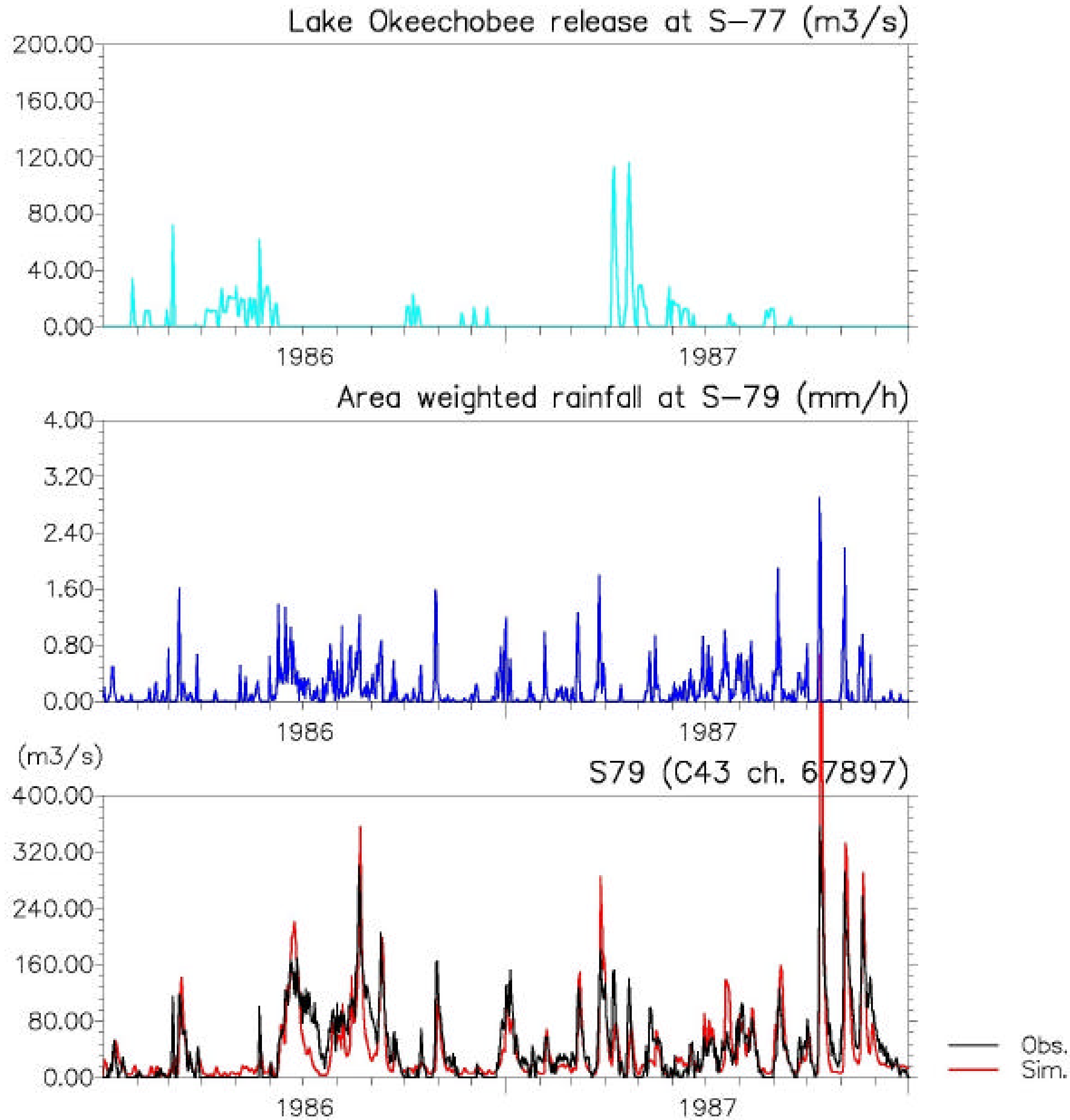

Figure 33 Simulated and observed flow (S-79), 1986-1988

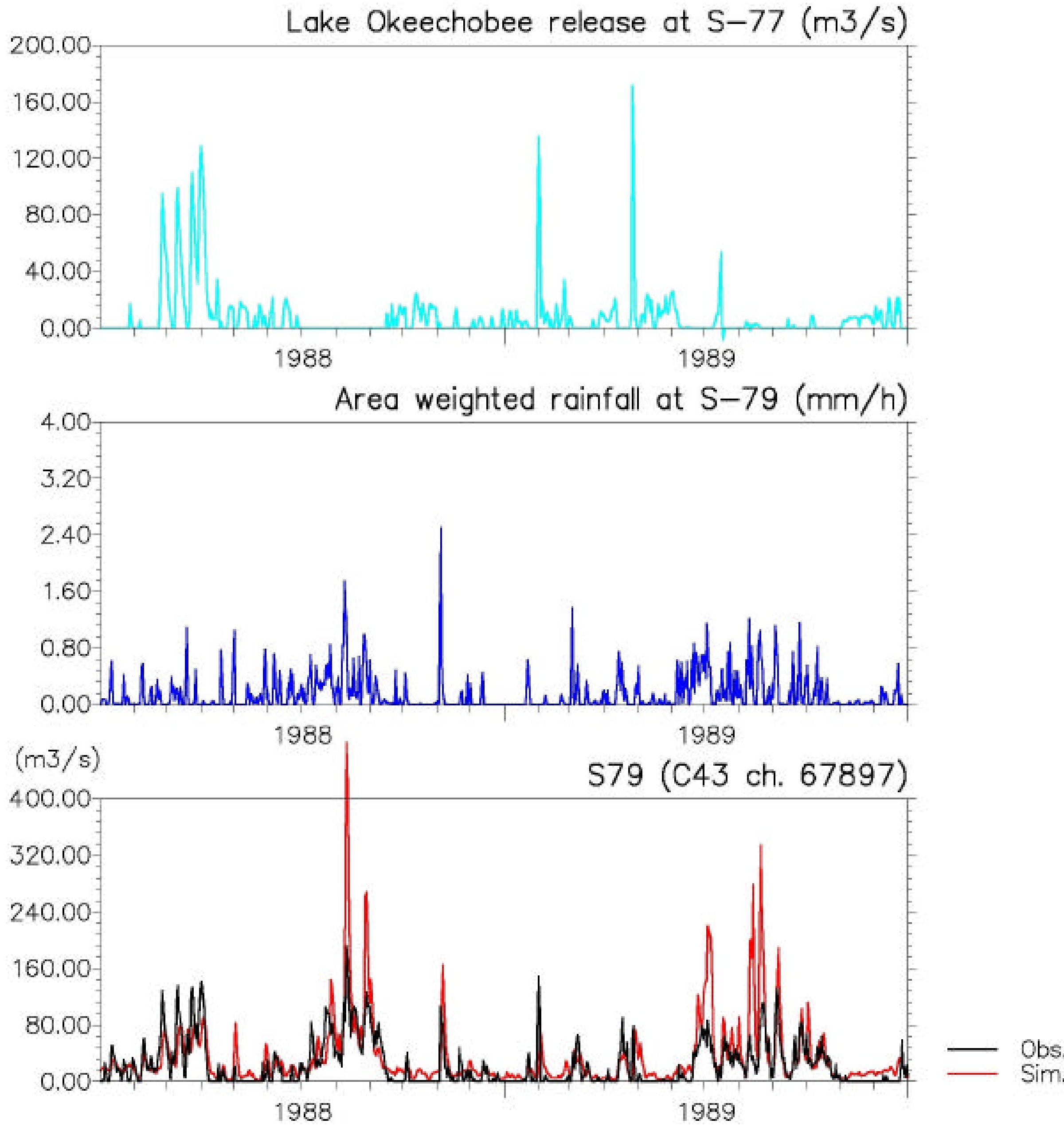

Figure 34 Simulated and observed flow (S-79), 1988-1990

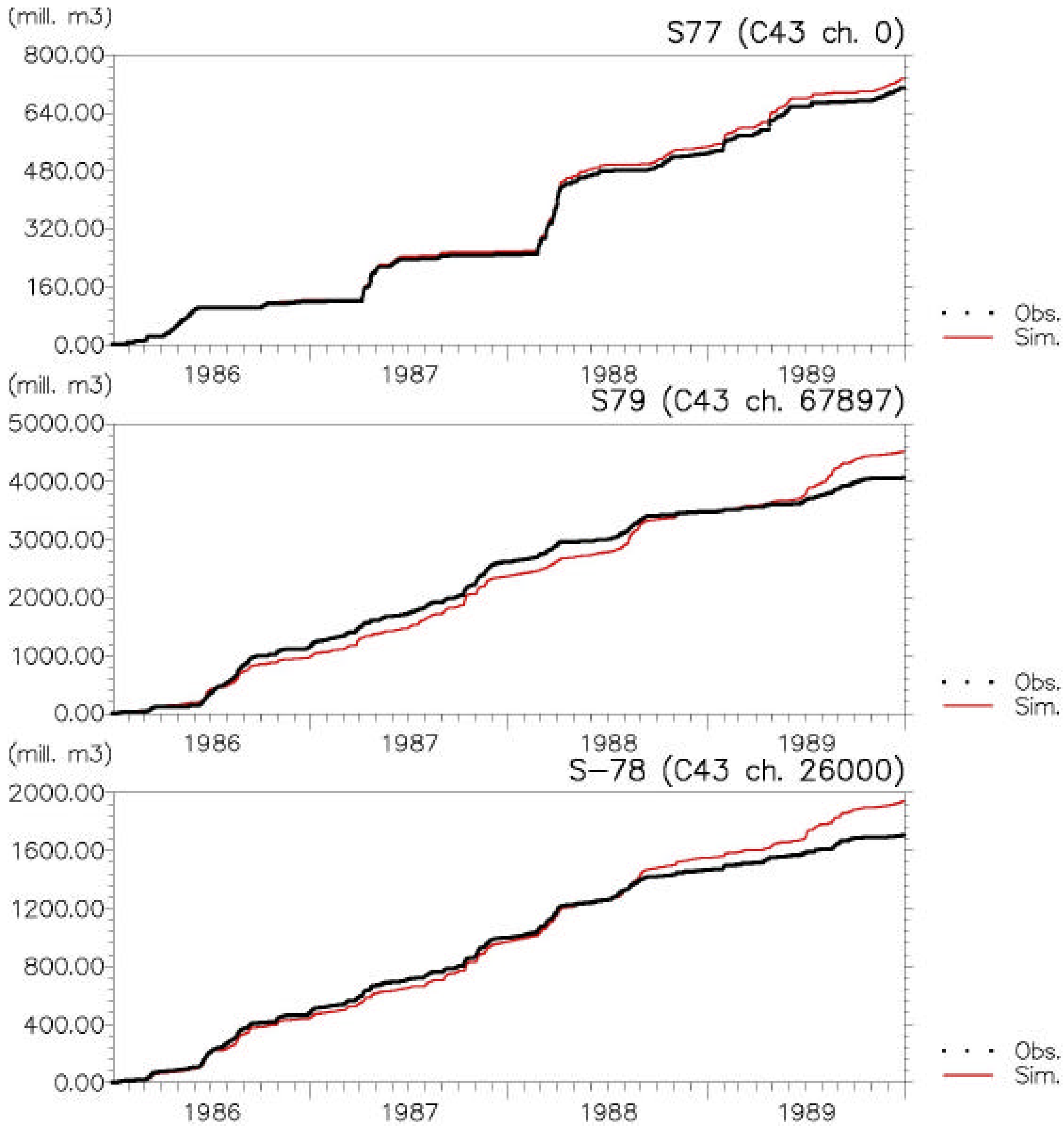

Figure 35 Accumulated surface discharge, 1986-1990

Table 15 Statistical calibration criteria, shallow aquifer (1986-1990)

Well id.	Rec. no	No. of observ.	Obs. min. (m)	Obs. max. (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-1027	1	25	7.88	9.06	96.0	60.0	92.0	48.0
HE-1077	9	23	7.16	8.42	82.6	47.8	73.9	47.8
HE-858	16	38	5.63	6.63	23.7	5.3	18.4	13.2
HE-857	17	48	4.03	5.16	68.8	45.8	87.5	41.7
HE-852	21	38	7.70	8.74	52.6	18.4	57.9	31.6
HE-851	22	62	6.95	9.03	98.4	79.0	100.0	64.5
HE-569	23	49	6.35	7.39	81.2	39.8	71.4	63.1
HE-558	24	639	4.35	5.09	13.9	23.5	0.0	0.0
HE-554	25	48	8.55	10.13	89.6	52.1	87.5	58.0
L-727	29	1435	3.96	5.39	24.4	8.1	11.7	7.8
L-1137	31	1441	4.87	6.63	93.7	61.4	89.2	48.3

Table 16 Statistical calibration criteria, deep aquifer (1986-1990)

Well id.	Rec. no	No. of obs.	Obs. min. (m)	Obs. max. (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-516	1	37	2.17	4.06	97.3	75.7	100.0	48.6
HE-517	2	1441	2.33	4.2	81.3	29.2	100.0	25.5
HE-555	4	61	4.11	7.99	67.2	59.0	100.0	34.4
HE-556	5	1431	1.99	7.82	94.1	67.6	100.0	27.8
HE-557	6	48	2.15	4.81	95.8	72.9	100.0	33.3
HE-559	8	48	5.11	6.65	58.3	18.8	43.8	12.5
HE-560	9	50	5.87	6.92	84.0	56.0	100.0	64.0
HE-620	10	46	3.19	5.01	58.7	34.8	91.3	30.4
HE-629	11	48	4.9	5.91	16.3	12.5	33.3	14.6
HE-853	12	38	7.53	9.24	36.8	5.3	21.1	2.6
HE-1028	13	25	7.87	8.99	84.0	56.0	80.0	48.0
HE-1029	14	25	7.87	9.03	84.0	56.0	80.0	48.0
HE-1076	17	22	5.3	7.79	77.3	40.9	81.8	28.2

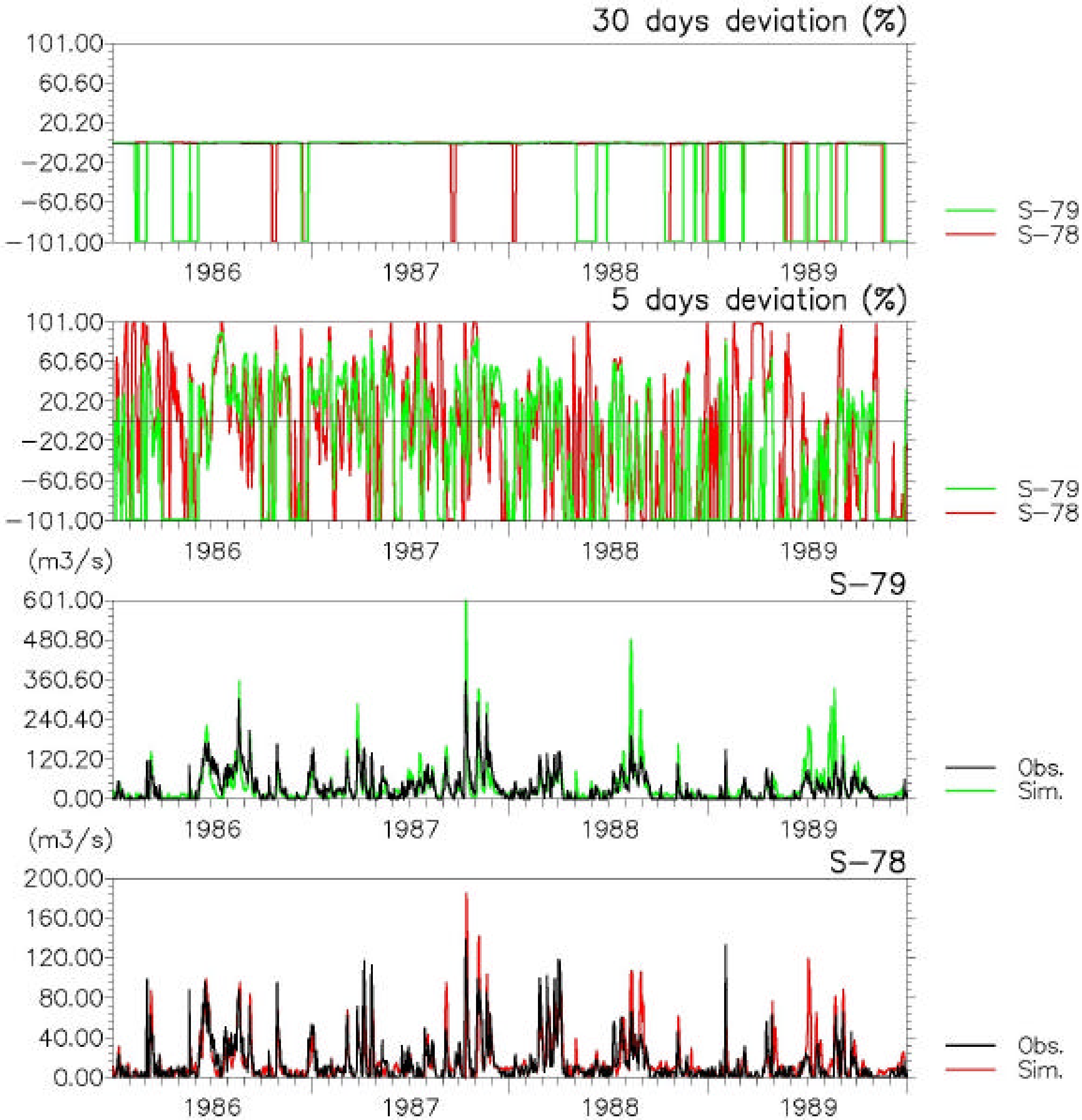

Figure 36 Statistical calibration criteria, C-43 discharge

3.6 Validation

The period 1994-1998 was chosen for model validation. All parameters applied in the calibration are unchanged during validation. Significant changes in land use and an increase in irrigated area must, however, be incorporated to properly represent the field conditions. The validation of the model can be used to investigate if the model parameters applied in the calibration period may be considered valid for the entire period 1986-1998 and if the model is capable of simulating the ongoing land use change in the basin. The irrigation canal network and groundwater wells locations are assumed identical for the two calibration periods implying that the irrigation canal system, but not necessarily the irrigation water demand, is unchanged.

Due to incomplete rainfall data for the period 1996-1998, the validation only covers the period 1994-1996.

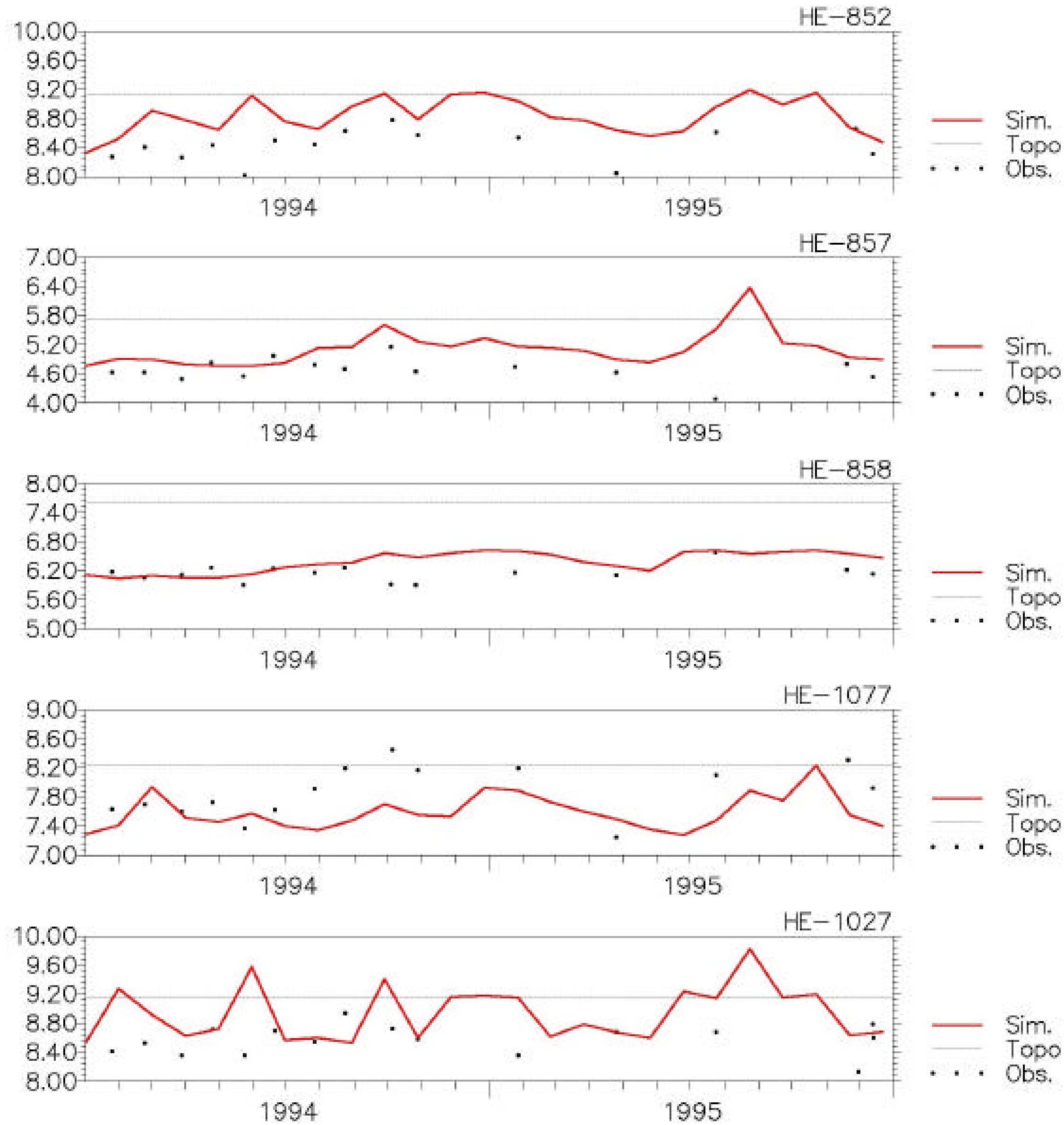

Figure 37 Simulated and observed potential head (shallow aquifer), 1994-1996 (I) - validation

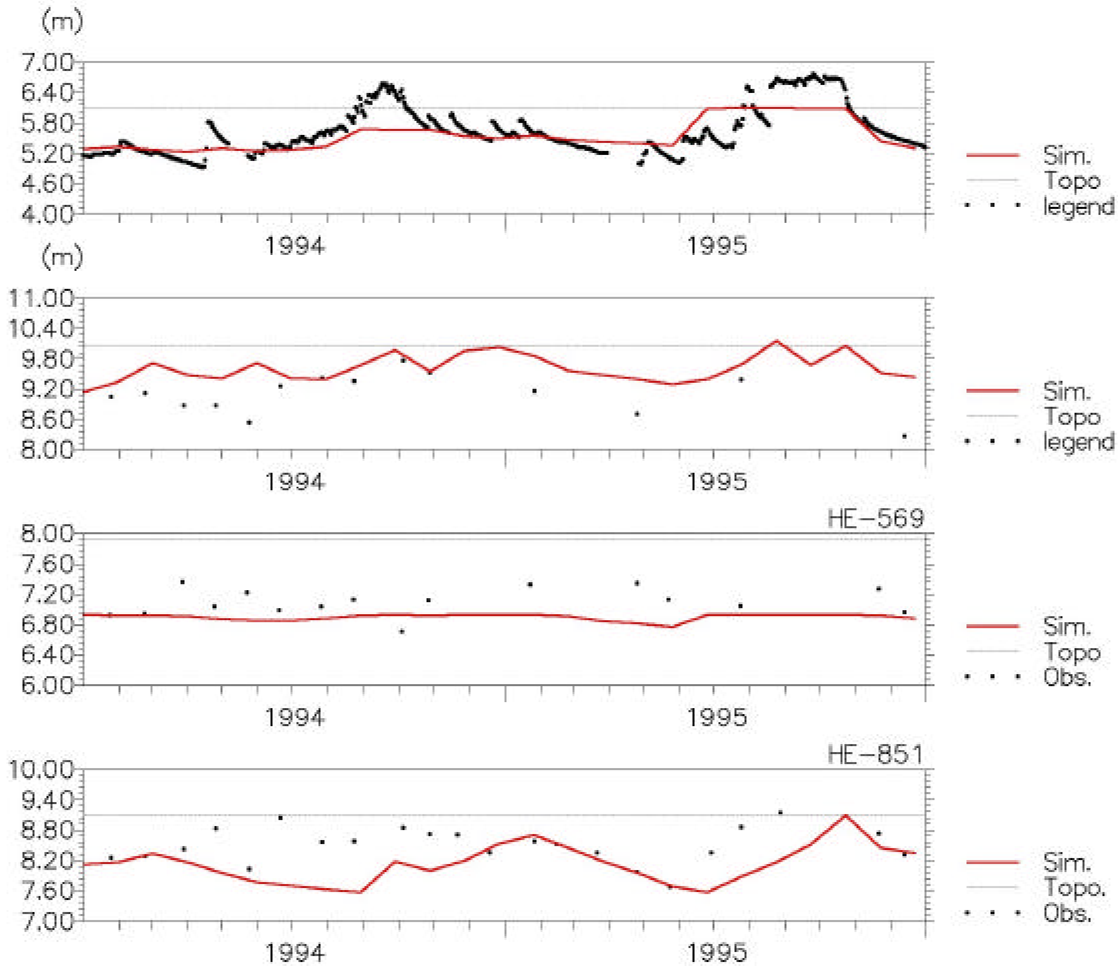

Figure 38 Simulated and observed potential head (shallow aquifer), 1994-1996 (II) - validation

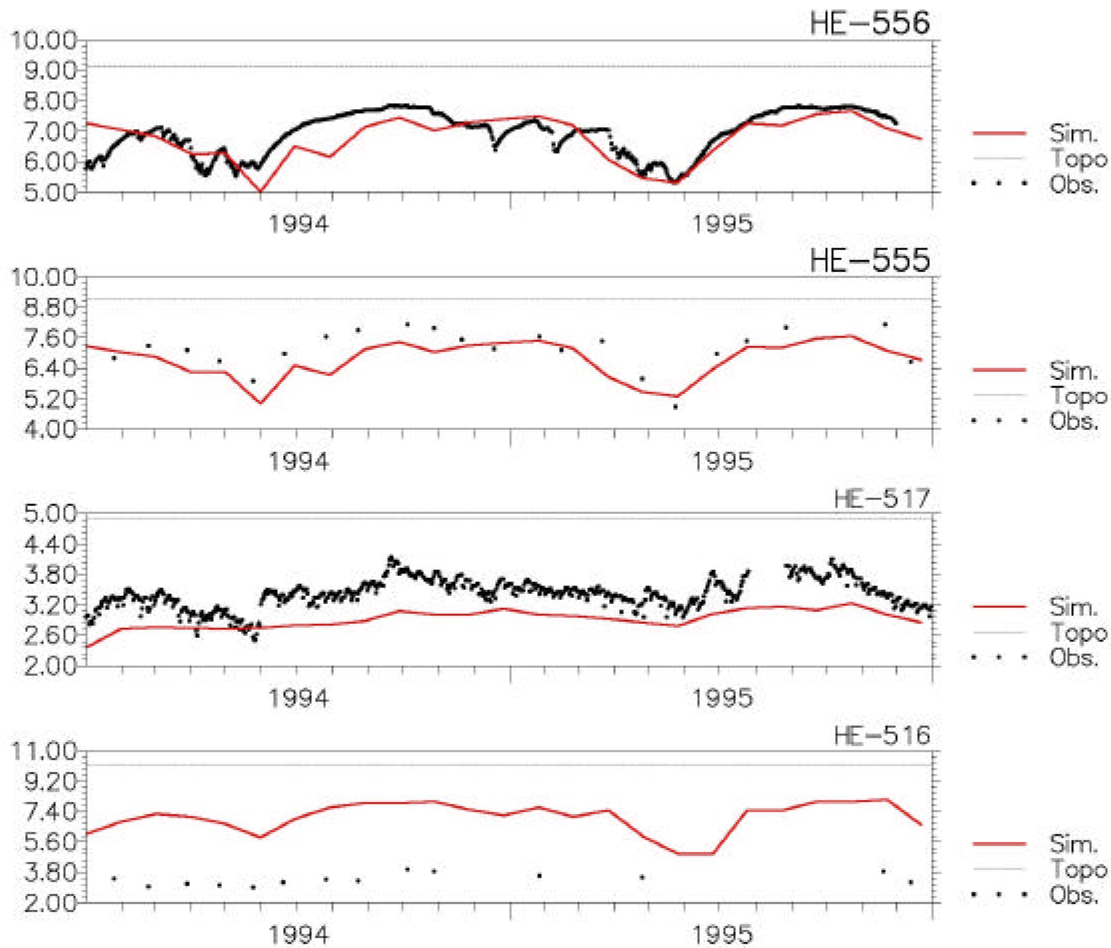

Figure 39 Simulated and observed potential head in deep aquifer (m), 1994-1996 (I)- validation

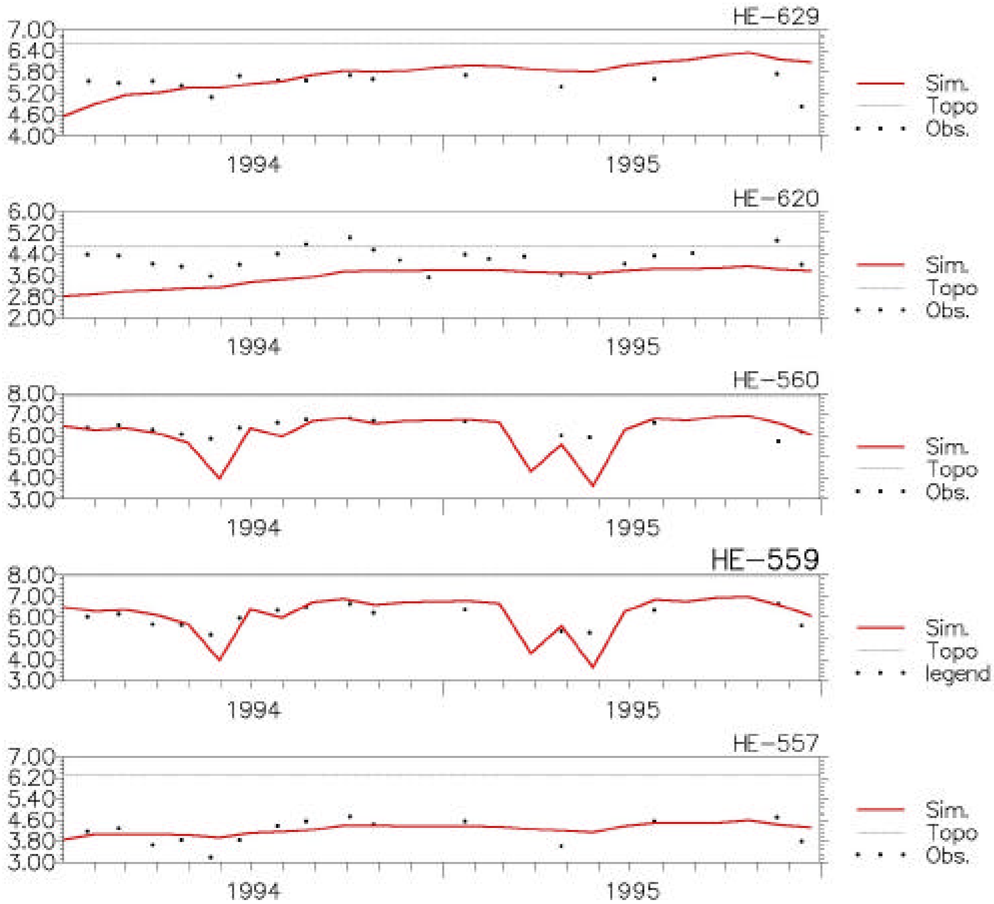

Figure 40 Simulated and observed potential head in deep aquifer (m), 1994-1996 (II) - validation

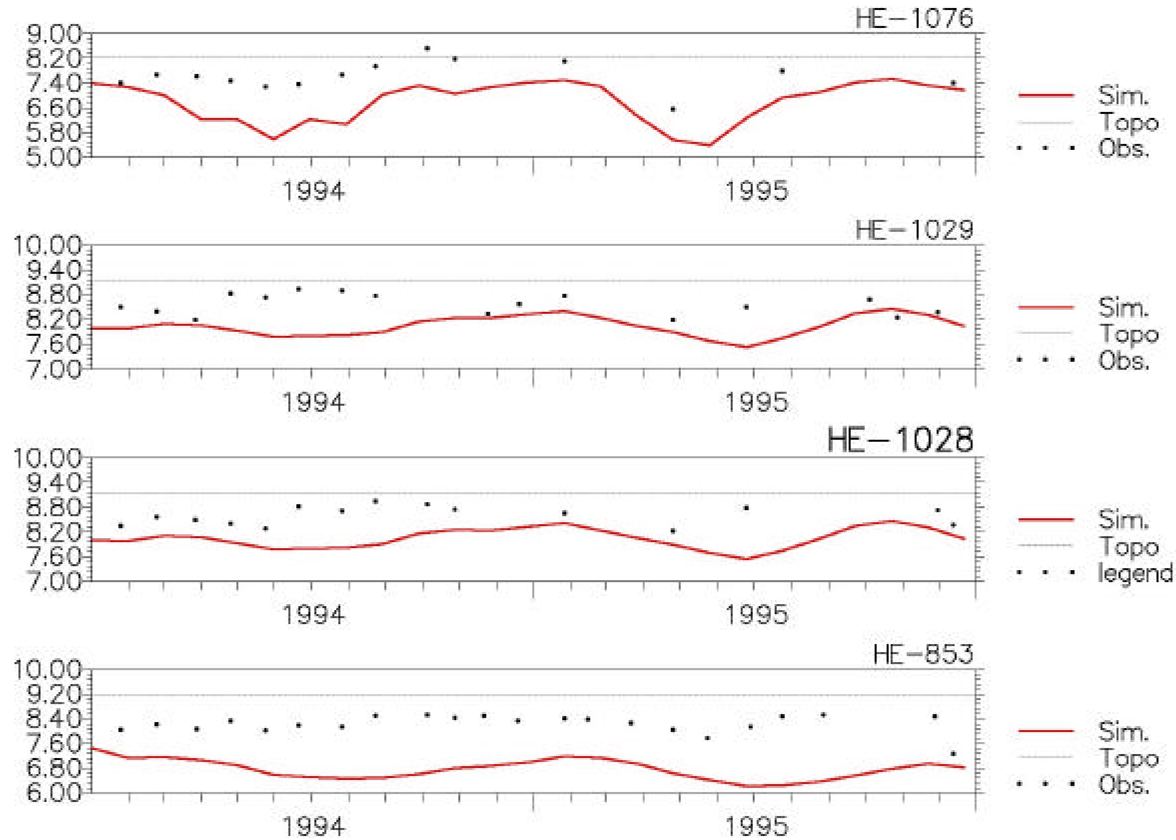

Figure 41 Simulated and observed potential head in deep aquifer (m), 1994-1996, (III) validation

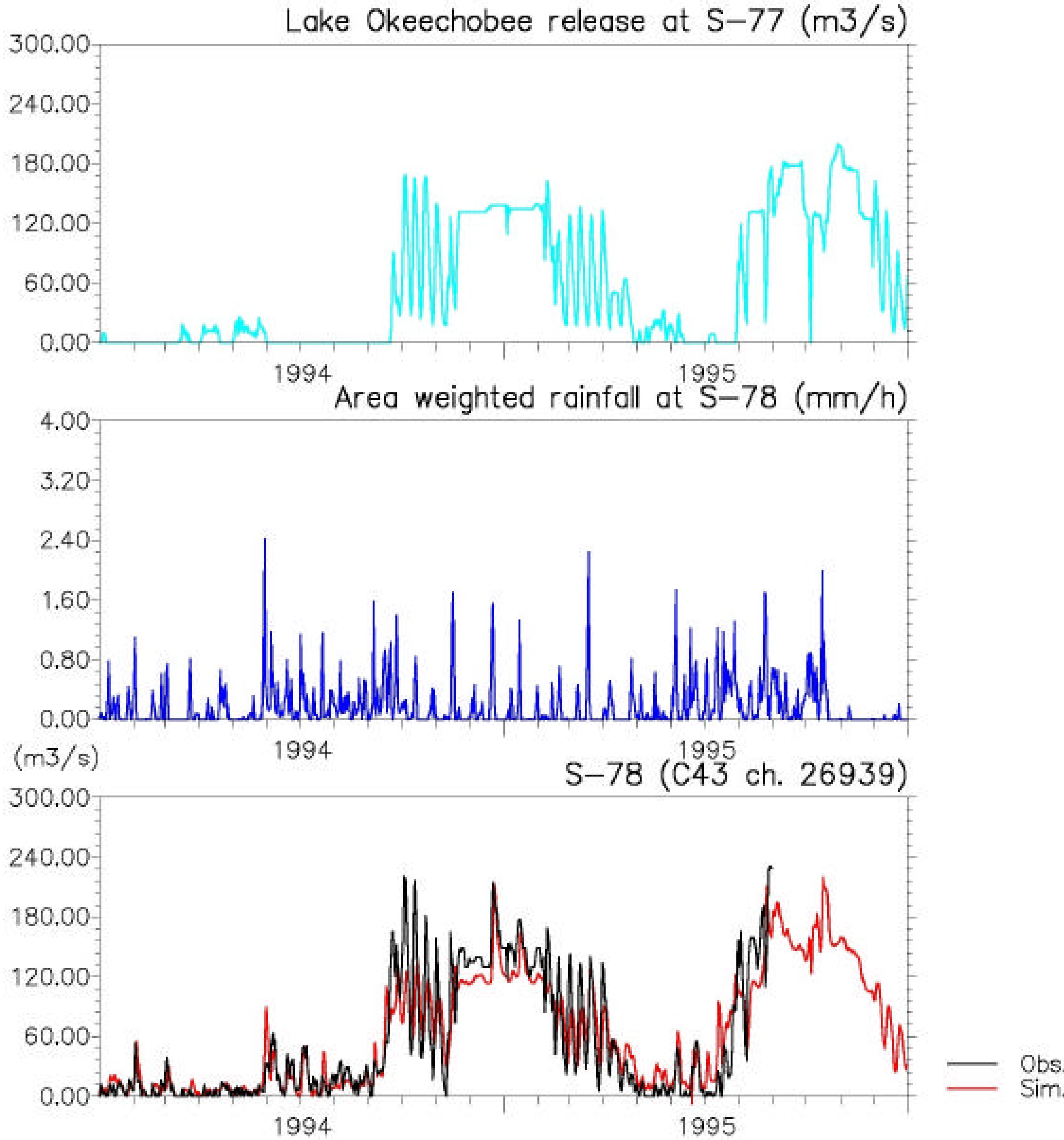

Figure 42 Simulated and observed flow (S-78), 1994-1996

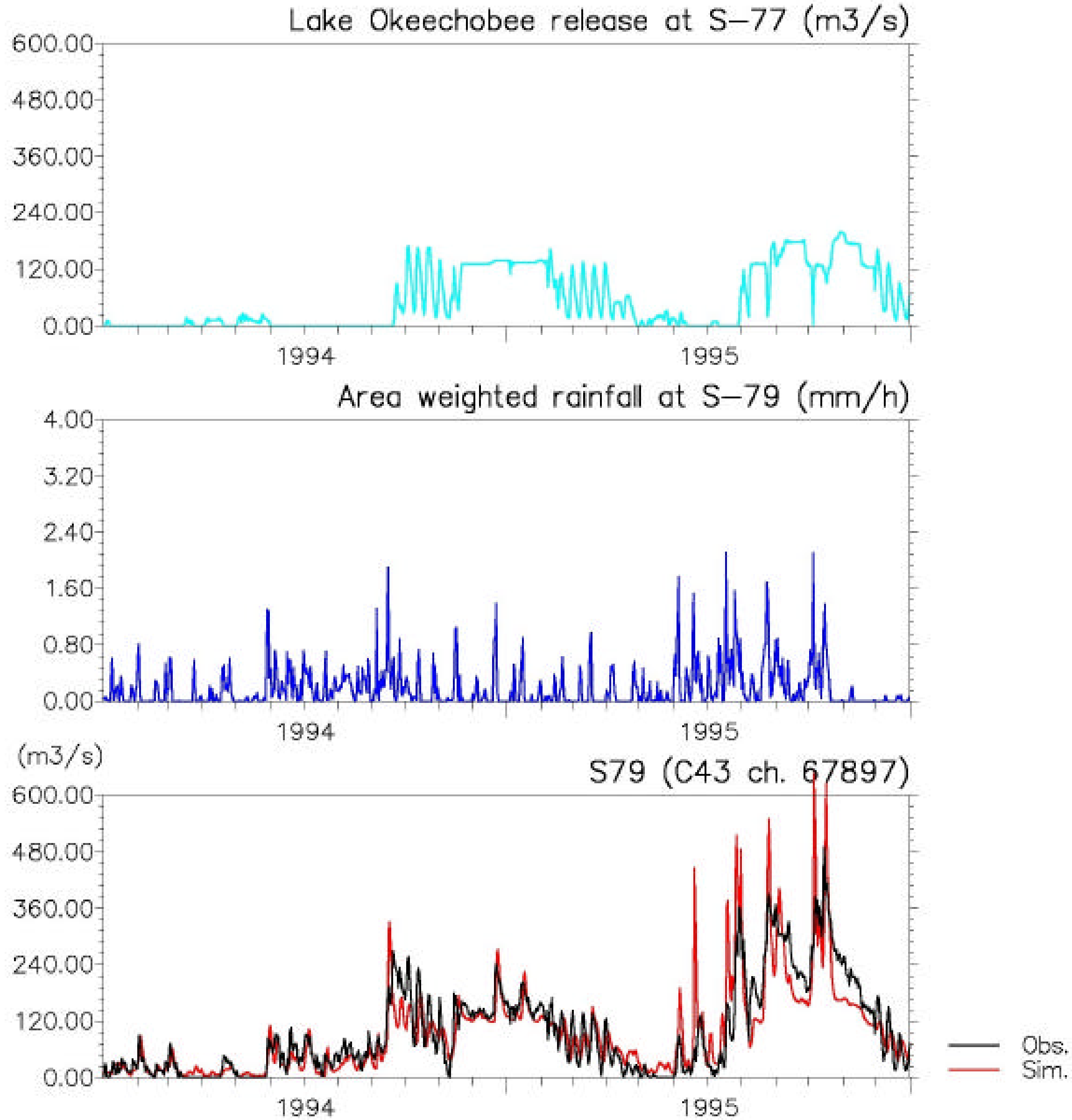

Figure 43 Simulated and observed flow (S-79), 1994-1996

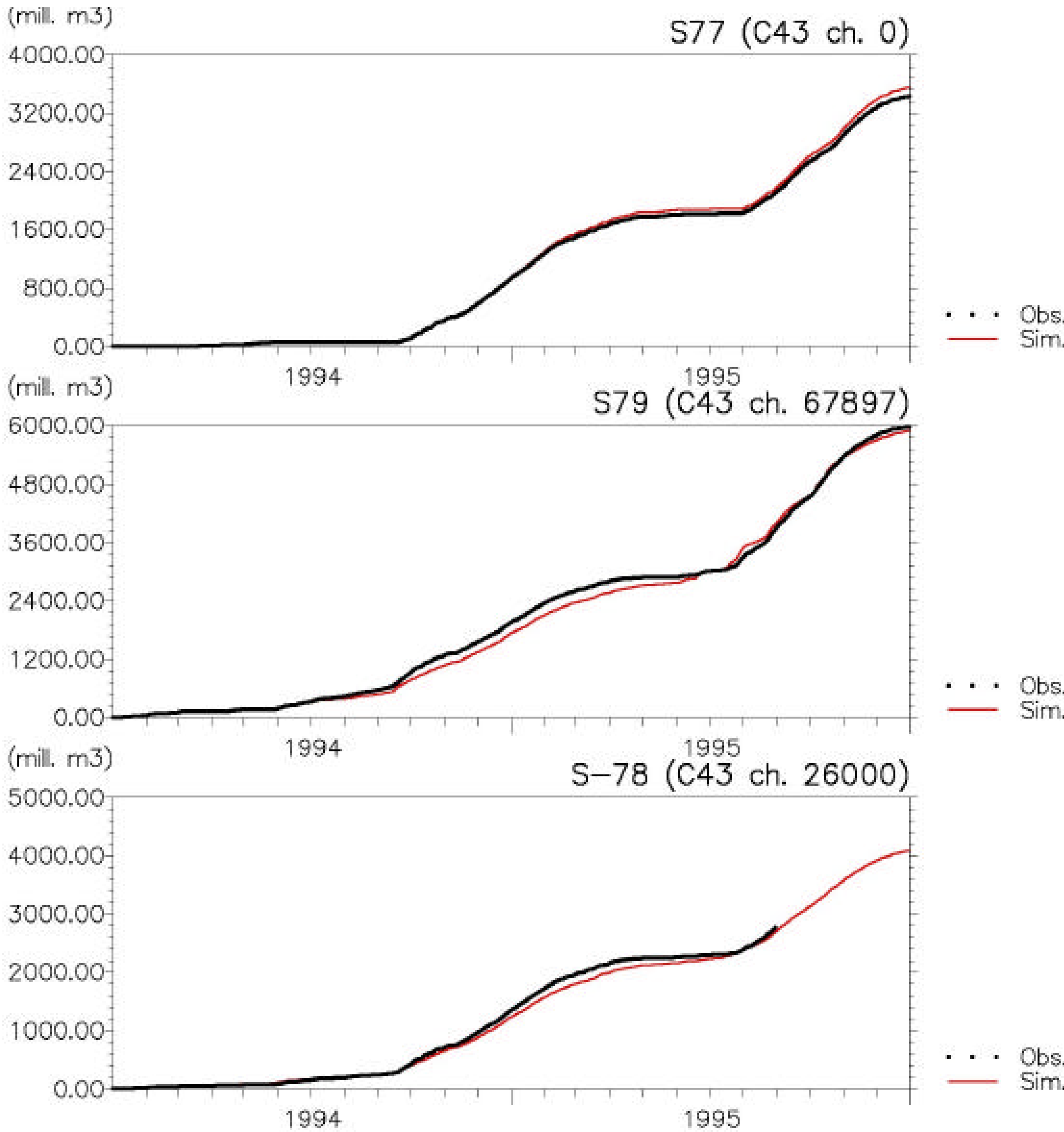

Figure 44 Simulated and observed accumulated discharge, 1994-1996

Table 17 Statistical calibration criteria, shallow aquifer (validation)

Well id.	Rec. no	No. of observ.	Obs. min. (m)	Obs. max. (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-1027	1	16	8.13	8.93	31.3	43.8	81.3	56.3
HE-1077	9	15	7.24	8.45	86.7	53.3	100.0	46.7
HE-858	16	15	5.90	6.58	53.3	13.3	26.7	33.3
HE-857	17	15	4.08	5.15	73.3	40.0	73.3	53.3
HE-852	21	15	8.01	8.78	73.3	33.3	60.0	46.7
HE-851	22	22	7.67	9.13	63.6	50.0	95.5	50.0
HE-569	23	16	6.70	7.36	18.8	43.8	68.8	56.3
HE-554	25	14	8.27	9.77	78.6	57.1	100.0	42.9
L-727	29	715	4.00	5.52	54.0	28.0	35.5	24.2
L-1137	31	679	4.92	6.77	81.7	48.7	66.7	34.9

Table 18 Statistical calibration criteria, deep aquifer (validation)

Well id.	Rec. no	No. of obs.	Obs. min. (m)	Obs. max. (m)	R1 (%)	R2 (%)	R3 (%)	R4 (%)
HE-516	1	14	2.90	3.98	78.6	57.1	92.9	57.1
HE-517	2	689	2.50	4.14	73.3	17.1	98.4	18.0
HE-555	4	22	4.11	7.99	90.9	77.3	100.0	31.8
HE-556	5	1431	1.99	7.82	95.7	78.3	98.3	40.5
HE-557	6	15	3.20	4.72	100.0	46.7	100.0	26.7
HE-559	8	16	5.18	6.61	62.5	75.0	68.8	43.8
HE-560	9	16	5.73	6.82	37.6	62.5	62.5	56.3
HE-620	10	22	3.51	5.01	45.5	22.7	63.6	22.9
HE-629	11	15	4.82	5.75	26.7	19.4	52.1	18.3
HE-853	12	22	7.25	8.53	8.4	13.5	31.6	17.8
HE-1028	13	46	8.21	8.94	46.7	16.7	26.7	6.7
HE-1029	14	46	8.18	8.92	43.8	18.8	31.3	37.5
HE-1076	17	61	6.54	8.51	50.0	21.4	57.1	14.3

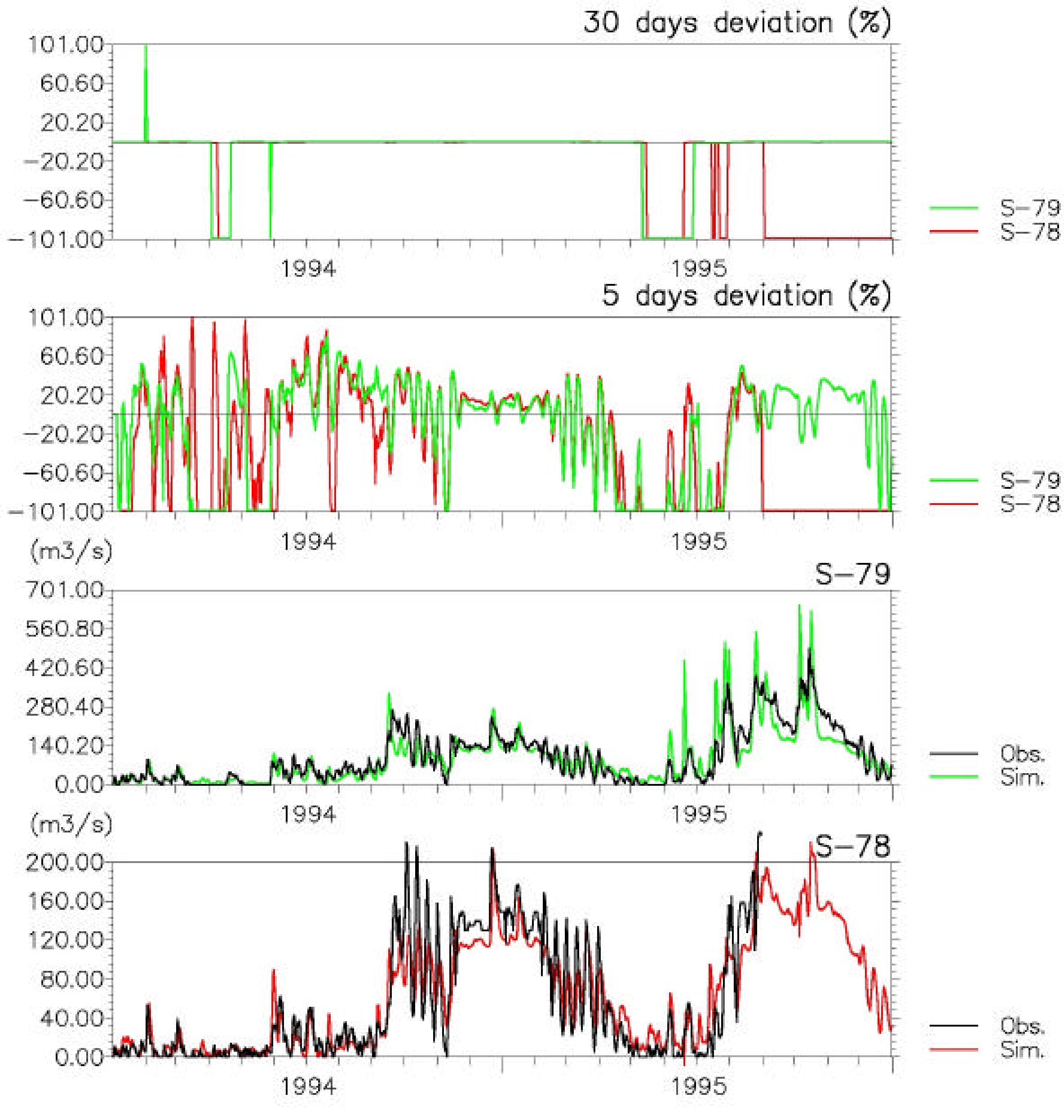

Figure 45 Statistical calibration criteria, C-43 discharge

3.7 Model uncertainty

A numerical model will be associated with uncertainty. It is desirable to quantify the uncertainty in order to interpret model results in a wider context as part of water management. In an integrated and distributed model it is difficult to assess the effect of single inputs or parameters on the different results from the model. Uncertainty should be regarded as specific to a certain output of the model e.g. discharge or groundwater tables at a given location.

The deviations between simulated and observed variables indicate uncertainties in both input data and model parameters, which must be considered when interpreting model results. To minimize uncertainty comparisons between effects of various water management scenarios should be done in terms of relative changes rather than absolute values. When interpreting the model results of a scenario relative to a base scenario, i.e. the difference between two sets of simulation results, the uncertainty originating from the approximate agreement between calibrated model results and field data, is minimized. This approach should be applied in impact analysis.

3.8 Sensitivity analysis

The purpose of a sensitivity analysis is to determine model parameters and model inputs, which are of primary importance to the model results. Input data or parameters, which are considered crucial to the model results, may be varied to quantify their effect on specific model results. By carrying out a series of model runs varying the parameter or input data within given ranges a general overview of the models sensitivity is established. If the model results are particularly sensitive to a specific parameter or input type the model results should accordingly be interpreted with the uncertainty associated with this particular parameter.

The Caloosahatchee ISGM is applied to estimate the water budget and the stress on the resource caused by irrigation. Looking at the overall water balance it is clear that evapotranspiration accounts for the largest water loss from the model area. It is thus essential to simulate the actual evapotranspiration. Accurate calculation of actual evapotranspiration depends both on the input data and the model parameters.

Sensitivity studies are carried out as an independent part of the study and is not a part of the model development, calibration and validation reported here.

3.9 Conclusions

The Caloosahatchee Basin Integrated Surface –Groundwater model is calibrated and validated against time series of observed potential head and C-43 discharge at S-78 and S-79. The groundwater observation wells are all located in the southern part of the model area. The discharge at S-78 includes the runoff from the eastern part of the basin and S-79 includes runoff from the entire model area.

The simulated C-43 canal flow at S-78 is close to measurements with respect to low flow, accumulated runoff and partly peak flows. At S-79 the low flow simulated by the model is generally over estimated. The absolute deviation is between 0 to 10 m^3/s while the relative deviation may be high during dry periods when the measured flow approaches zero. The relative measures (accumulated for 5 days and 30 days respectively) shows that dry period flow deviation fluctuate. The highest relative deviations are higher than the calibration targets. It may be indicative of not only calibration accuracy but also uncertainty in low flow measurements applying rating curves. The canal flow calibration criteria based on relative deviation should be considered in connection with the absolute differences.

The model describes the increase and subsequent recession in river flow but the absolute peak level is either underestimated or more often overestimated at some rainfall events. This is, however, partly attributed to limitations in input data and apparently too high drainage flow at some storm events. Comparing rainfall, Lake Okeechobee releases and the measured river flows it is seen that high river flows are apparently not always driven by rainfall and boundary inflow. This indicates that the rainfall station network may not be sufficient to describe all events or that the flow measurement is not complete.

During parts of the calibration period the simulated hydrographs at S-78 and S-79 are very close to the observed. The model describes very accurately the basin runoff (1986, 1987 and partly 1988). For other periods clear deviations are seen. With the applied set of parameters, the model is thus capable of capturing runoff for the simulation period in general, while deviations are seen for shorter durations. Further adjustment of parameters to simulate single storm events may thus have adverse effects for the remaining part of the period.

No data exists to describe gradual changes in the basin, e.g. canal network or land use, during the simulation period. Effects of ongoing changes can not be addressed as part of calibration.

The simulated groundwater potential heads of the shallow aquifer correspond very well to the observation time series with respect to average ground water level. The dynamics is not entirely captured by the model at all observation wells locations. This applies especially to some observation wells in the deep aquifer. One reason for lack of water table fluctuation is drainage. Drainage levels are specified for areas assumed drained. When the groundwater table rises above the drainage level the groundwater volume is routed to receiving points in the basin. Receiving points could be depressions, wetlands or canals. Consequently the drainage level reduces the maximum level of the groundwater table.

Figure 46 shows observed and simulated potential heads at two locations where observations exist for both aquifers. The deep aquifer is more dynamic than the shallow aquifer. The most likely reason for the head fluctuations in the deep aquifer is the drawdown from nearby wells. The low potential heads do not seem to affect the head of the shallow aquifer, which indicates that the vertical hydraulic conductivity is very low. As withdrawal data for individual wells are not available it is not possible to simulate the local drawdowns. The examples show that the simulation of deep aquifer head fluctuations can only be simulated by including individual wells and withdrawal rates in the model and not by further calibration of hydraulic properties.

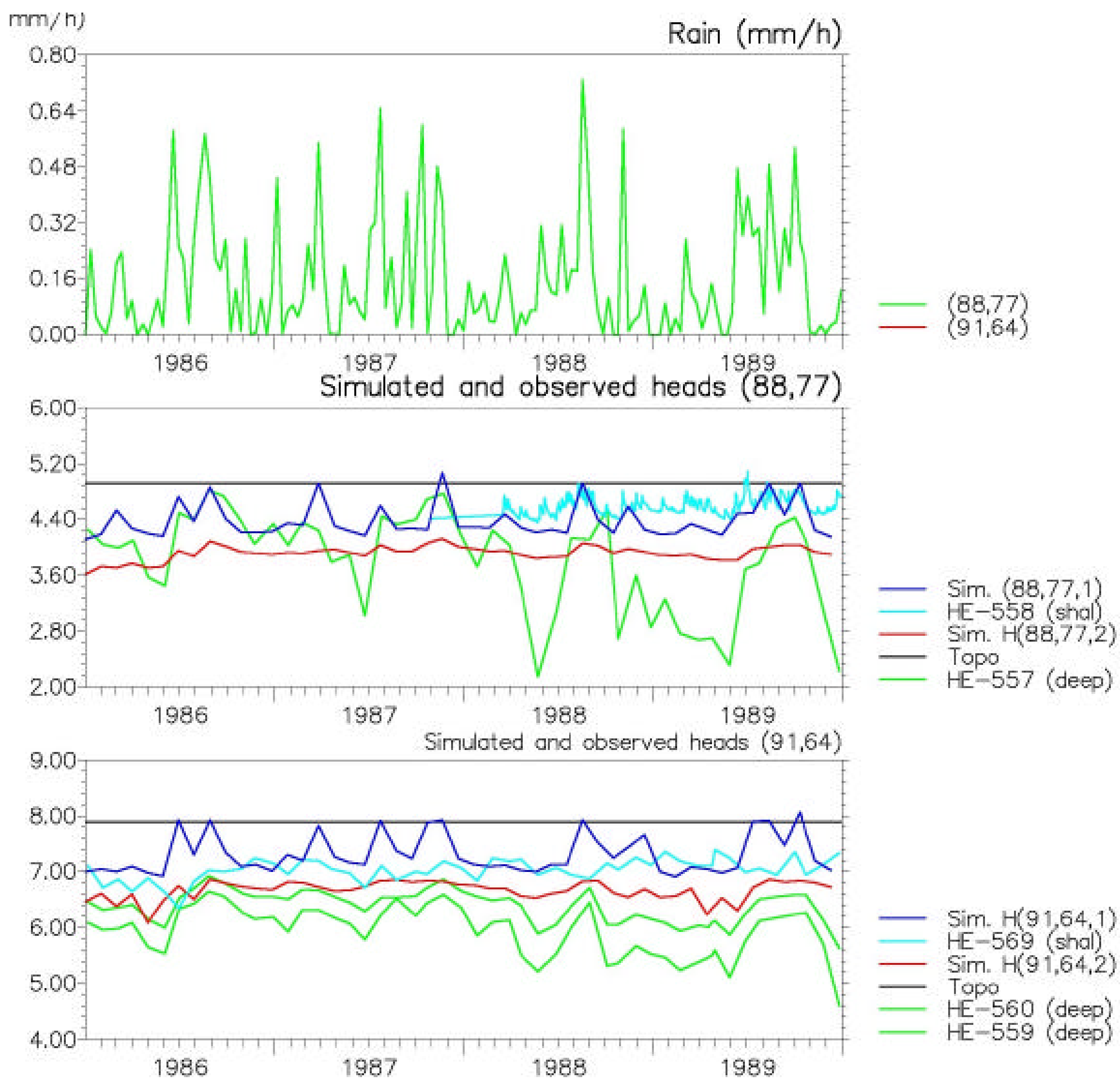

Figure 46 Comparison of potential heads in shallow and deep aquifer (m)

The average level of simulated deep groundwater potential heads corresponds to observed levels with the exception of two locations where the deviation is more than 5 feet. The deeper ground water table is less dynamic than the shallow and the model generally simulates the maximum and minimum levels accurately. The dynamics is underestimated at a few locations. The statistical criteria show that some wells do not meet all the calibration targets (R1-R4 to be satisfied for 75 % of the simulation period). The R4 criteria is not met for the wells in general - even at wells where a visual evaluation of the simulated and observed values suggest a close agreement.

The validation period serves to establish whether the model parameters derived during calibration are generally valid. Due to significant changes in cropped areas the land use and irrigation set-up must be modified from the calibration to the validation. The validation period is compared to the calibration period characterized by more frequent releases of water from Lake Okeechobee. The changes will test the versatility of model parameters given different conditions.

As for the calibration period the river discharge is occasionally underestimated at peak flows while the dry period flow is simulated to the highest attainable level. No alteration in ground water levels is seen and the model simulates the average level and partly the dynamics at most shallow aquifer observation wells. The difference between simulated and observed time series of potential head in the deep aquifer varies. A close agreement is found at some locations while significant deviation is found at others.

No systematic changes in the simulated values compared to observed values are found, which indicate that the calibration parameters may be assumed valid for other period including future predictions.

The success of model calibration must be seen in connection with the uncertainties in input data. When formulating the targeted maximum deviation it must be compared to the uncertainty in input and calibration data and the complexity of the hydrological system.

Given the available field data and the general basin characteristics the calibration and validation is considered satisfactory. The calibration reflects that priority has been given to simulate the surface domain and the upper part of the aquifer system with emphasis on dry period conditions.

To minimize the uncertainty of model simulations in relation to impact analysis it is recommended that model results are interpreted in terms of changes relative to a base scenario.

4 MODEL RESULTS

4.1 Water balance

4.1.1 Total water balance

The water balance is an essential result of the modeling. It provides information on available resources and demands in the basin.

Overall water balance figures covering the entire basin and several years of simulation may not properly describe the large temporal and spatial variations in water availability and demand.

Consequently the flow and storage in the surface water and groundwater is insufficient to meet the demand and water is released from Lake Okeechobee. To reduce the need for Lake Okeechobee water it is necessary to store an additional water volume and make it available for irrigation.

MIKE SHE incorporates both surface and sub-surface flow and a total water balance for the Caloosahatchee basin may be extracted from the simulation results. Water balance may be extracted for:

- The entire basin or sub-basins
- The entire simulation period or any period within it.

A total water balance including all model components or specific components e.g. groundwater

The water balance for the entire basin or sub-basins can be formulated as:

$$P - E = (Q_{S,out} - Q_{S,Okee}) + (Q_{G,out} - Q_{G,in}) + \Delta S + R \qquad \text{(eq.1)}$$

P : rainfall

E : evapotranspiration

$Q_{S,Okee}$: Surface water inflow (release from Lake Okeechobee into C-43)

$Q_{S,out}$: Surface water flow out of the model area (Okeechobee release and basin runoff)

$Q_{G,in}$: Groundwater flow into the model area

$Q_{G,out}$: Groundwater flow out of the model area

Δ S : Change in storage of surface water, unsaturated zone and groundwater ($\Delta S_s + \Delta S_{uz} + \Delta S_{sz}$)

R : External sink/sources (e.g. irrigation water supplied directly from outside the model area)

Irrigation is not added as a sink-term in (eq.1). Water diverted from canals or abstracted from the groundwater is used internally and will add to the actual rate of evapotranspiration. Additional water losses due to irrigation will thus be represented by a higher E in the total water balance.

What is of particular interest in the Caloosahatchee model is the proportion of water discharged at S-79 originating from Lake Okeechobee and from basin runoff ,respectively.

Table 19 Total water balance for the calibration period 1986-1990 inches (mm).

Year	P	E	$Q_{S,out}$-$Q_{S,Okee}$	$Q_{G,out}$-$Q_{G,in}$	Δ S+R
1986	51 (1286)	47 (1190)	3 (79)	1 (19)	0 (-2)
1987	60 (1512)	48 (1213)	9 (238)	1 (14)	2 (47)
1988	49 (1232)	47 (1182)	2 (43)	1 (15)	0 (-8)
1989	48 (1228)	44 (1130)	4 (89)	1 (14)	0 (-5)
Total	208 (5258)	186 (4715)	18 (448)	3 (62)	1 (32)

The water balance for the calibration period 1986-1990 shows that evapotranspiration losses account for approximately 90 % of the rainfall in the basin. There is a net outflow from both river and groundwater. The storage change from wet to dry years is quite small. Despite the use of irrigation water there is an additional storage available every year.

Annual water balances may be supplemented by water balances for shorter periods focusing on dry conditions.

4.1.2 Canal water balance

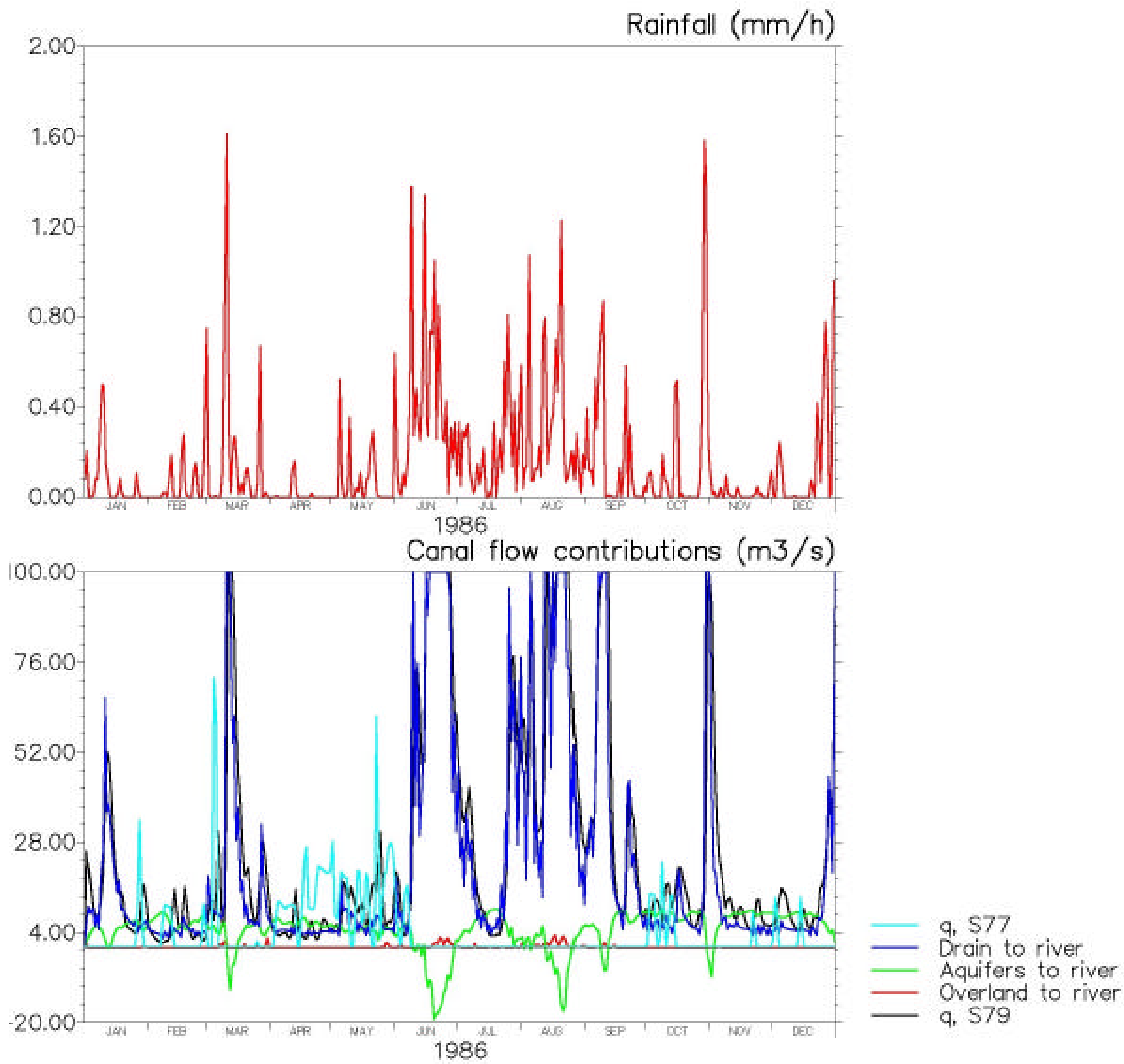

Figure 47 Canal flow contributions at S-79 (1986)

The river discharge is the sum of the upstream flow boundary at S-77 and the basin runoff. The runoff is separated into three individual terms describing the exchange with aquifers, overland sheet flow and groundwater drain flow. Groundwater drainage is the dominant contribution during wet periods and it determines the peak flows. The seepage into the river from the aquifers is controlled by the water level gradient. Consequently the base flow is almost constant at normal river water levels. During storms the aquifer is recharged when the river water level rises. The overland contribution is insignificant and is only seen at storms.

4.2 Irrigation

Irrigation demand and supply is calculated for each computational node of the irrigated areas. Results may be extracted either as time series for each irrigated grid or as maps for the entire model area at a given date.

4.2.1 Total basin irrigation

The simulated irrigation demand may be retrieved as time series for the individual computational cells or as a total for all irrigated land.

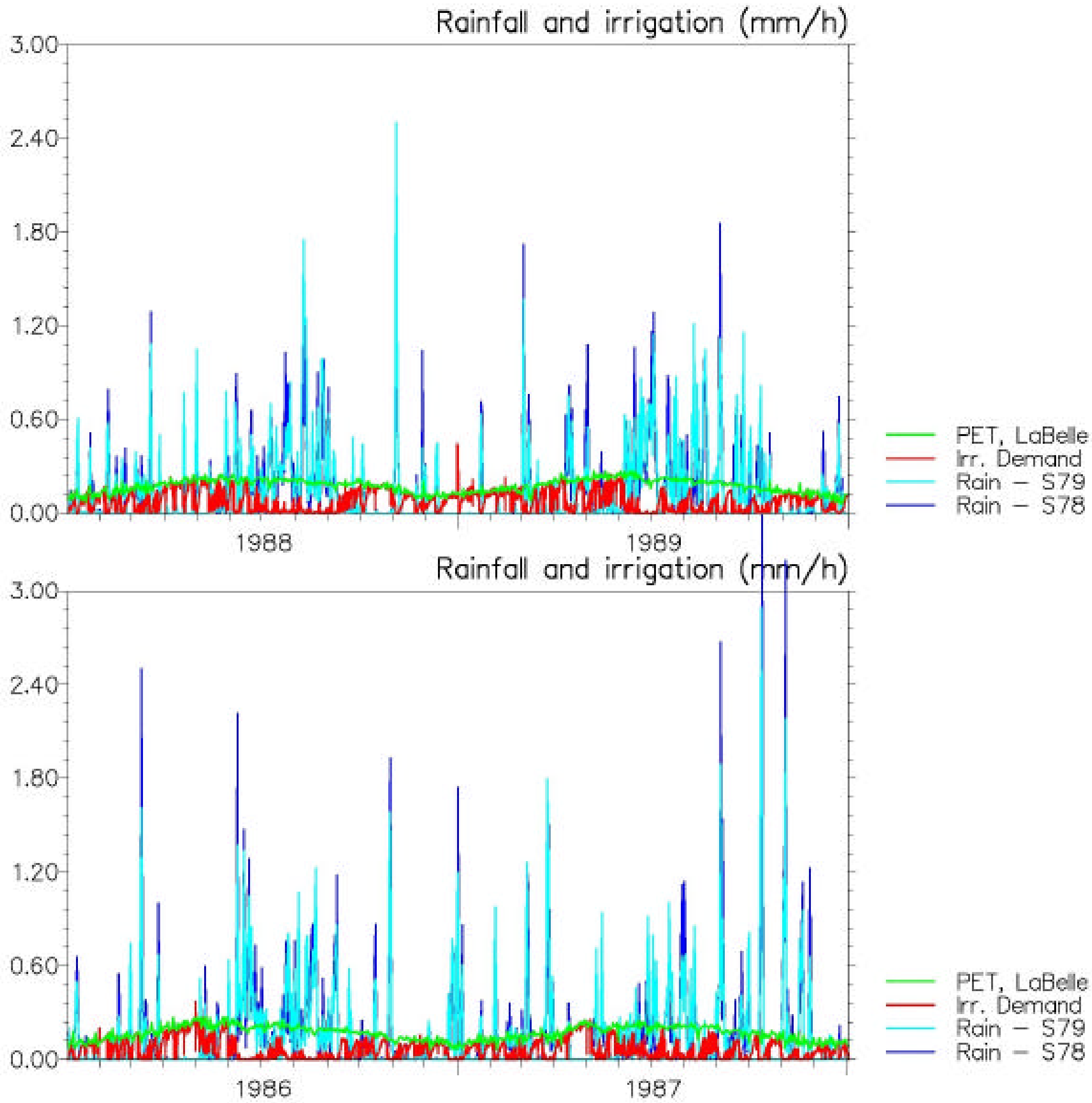

Figure 48 Time series of total irrigation demand, rainfall and potential ET, (1986-1990)

The irrigation demand is clearly controlled by rainfall and evapotranspiration. The demand increases significantly in dry periods and approximately equals the potential evapotranspiration rate. As the demand is directly linked to the soil water content infiltration following rainfall events causes a decrease in irrigation demand.

Table 20 Summary of simulated hydrology on irrigated areas, 1986-1990

Crop	Rainfall [inches] [(mm)]	Pot. ET [inches] [(mm)]	Act. ET [inches] [(mm)]	Irr. water demand [inches] [(mm)]	Irr. canal supply [inches] [(mm)]	Irr. GW supply [inches] [(mm)]	External supply [inches] [(mm)]
Citrus	211 (5356)	232 (5888)	222 (5650)	138 (3504)	67 (1698)	65 (1653)	0 (0)
Sugar cane	188 (4787)	226 (5742)	216 (5491)	128 (3890)	110 (2803)	0 (0)	15 (382)
Truck crops	199 (5066)	232 (5904)	228 (5781)	145 (3679)	91 (2312)	48 (1226)	4 (98)

External sources includes water pumped directly from Lake Okeechobee or groundwater withdrawn from deep aquifers not represented in the model (Floridan aquifer).

If the supply from canals, wells and external sources is summed up it is slightly less than the total demand, which is an indication of shortage in the simulation period. Shortage is not a common phenomenon in the Caloosahatchee model and occurs only in restricted areas in short period of time.

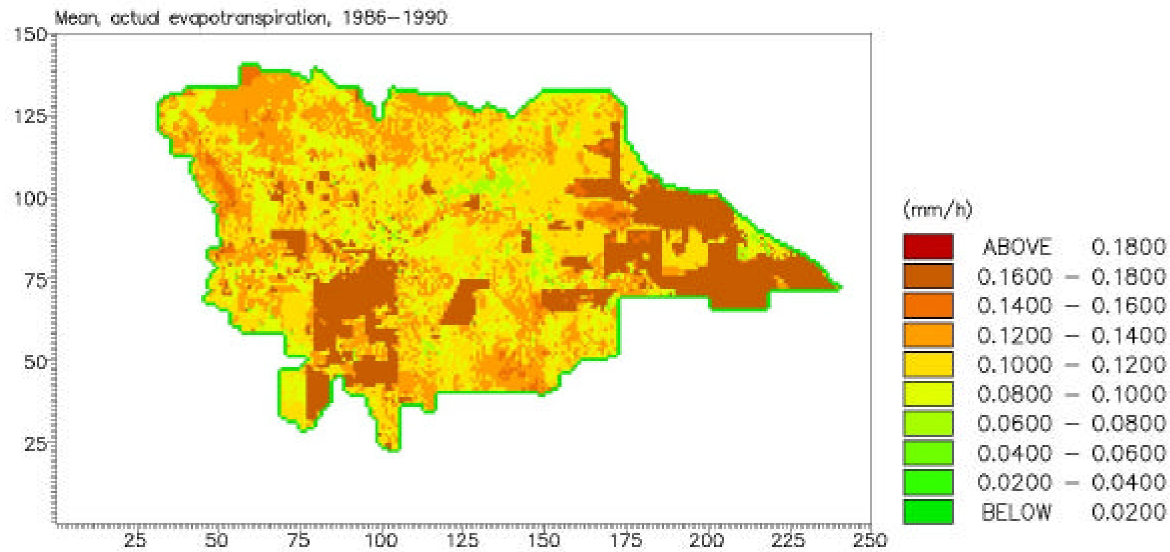

Figure 49 Simulated mean actual evapotranspiration, 1986-1990.

The distributed mean actual evapotranspiration for the Caloosahatchee model shows a clear increase in area, which are irrigated. In wet non-irrigated areas, e.g. Telegraph Creek catchment in the northwestern part of the model area the rates is kept higher due to free water surface evaporation and higher root zone soil water content.

4.2.2 Field scale irrigation

The irrigation module simulates irrigation demand, irrigation supply, unsaturated zone flow and groundwater recharge in every grid cell in the model. Depending on the land use and the local conditions the irrigation supply varies in both time and space.

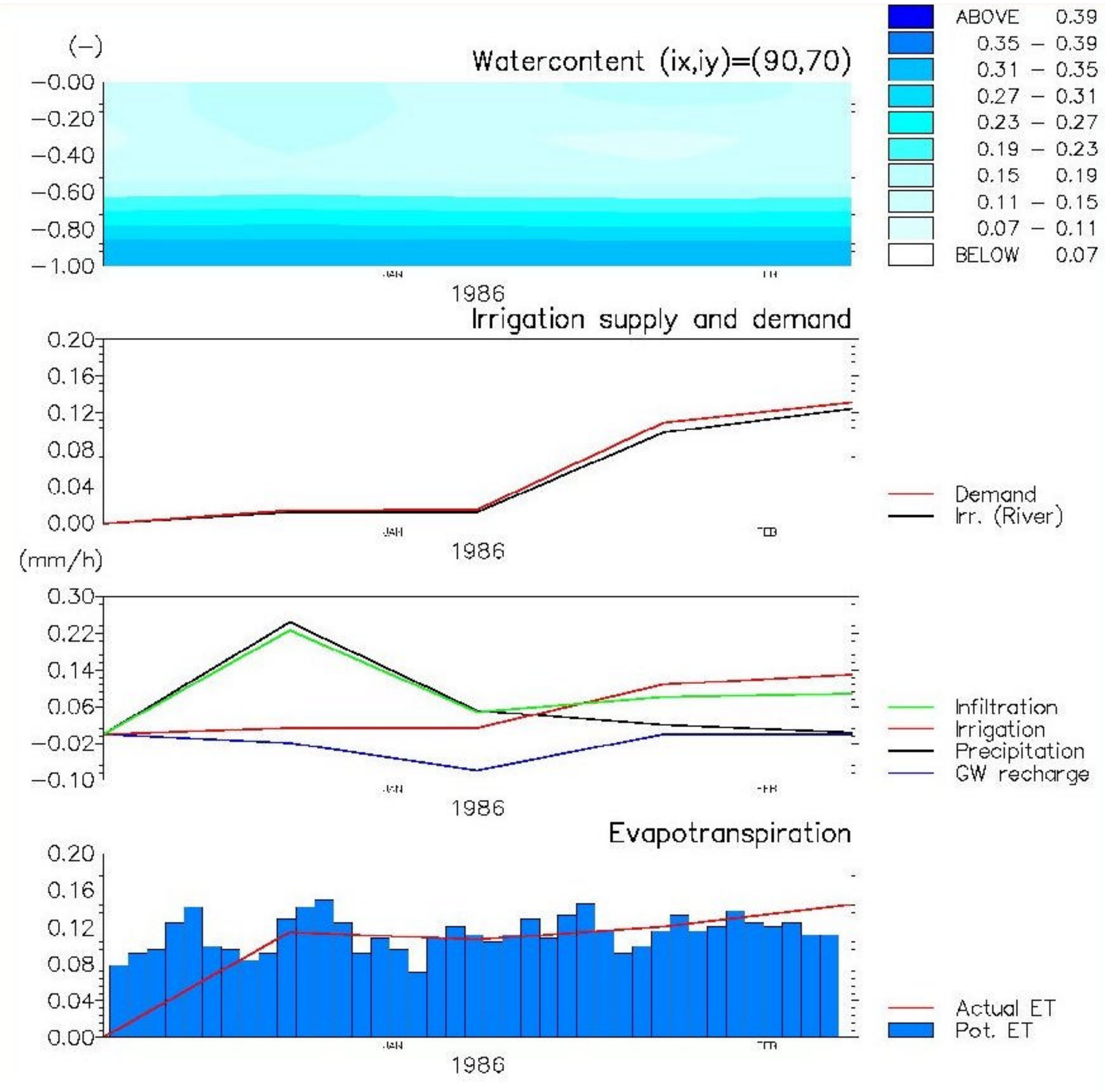

Figure 50 Irrigation and ET in irrigated (citrus) area

4.2.3 Irrigation demand and canal discharge

The canal discharges and water levels are affected by the allocation of water for irrigation. The dry period flow at S-79 clearly shows the effect of diversions to the irrigation canals. The volume released from Lake Okeechobee in dry periods is gradually used for irrigation as it flows through C-43.

The canal irrigation supply may be plotted as negative flow at S-79 (Figure 51).

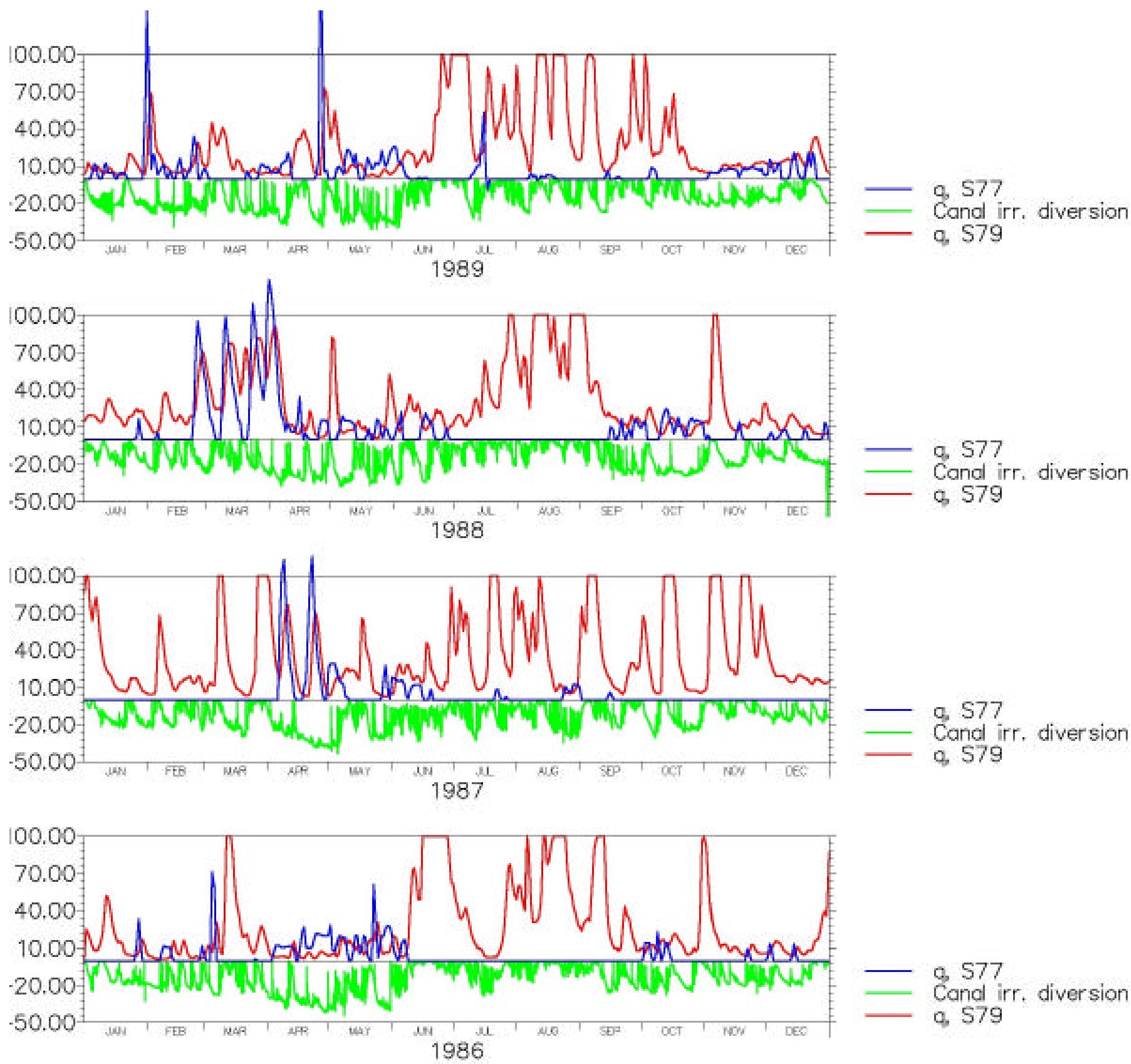

Figure 51 Simulated S-79 discharge, releases at S-77 and canal irrigation diversion

5 CONCLUSION

A highly advanced and comprehensive integrated hydrological model has been developed for the Caloosahatchee basin based on the MIKE SHE modeling system. The model includes subsurface flow in terms of groundwater and unsaturated zone flow, surface water in terms of overland and canal flow and a fully dynamic coupling between the components of the model. Furthermore a fully distributed irrigation module is applied linking irrigated land and irrigation sources in the basin. Meteorological data, topographical data, soil physical data, land cover data, vegetation data, hydrogeological data, canal and hydraulic structure data and irrigation permit data has been used to establish the model.

The hydrology of the basin has been conceptualized prior to developing the ISGM model. Due to the complex hydrology of the basin, the model scale (1500 ft size) and the quantity of available field data a simplified description has been adopted. While attempting to maintain the major flow processes of the basin the model has been developed to simulate the fully dynamic flow and exchange comprising:

- Groundwater (4 layer geological model and two layer computational model)
- Unsaturated zone (5 characteristic soil columns)
- Evapotranspiration(10 characteristic vegetation cover classes)
- Overland flow (fully distributed controlled by overland water level and slope)
- Canals (primary irrigation and drainage canals including major hydraulic structures)
- Irrigation (irrigated areas and the conjunctive use of surface water and groundwater)

5.1.1 Calibration

As discussed in section 3.9 the model is calibrated against surface water discharges and groundwater heads in the upper and lower aquifer, respectively. The accuracy of the calibration has been evaluated from the models ability to describe the average groundwater heads and canal flows and secondly the dynamics.

The mean low flow of C-43 is simulated with a small absolute deviation while the relative error is high as the flow approaches zero. Peak flows are generally well described by the model.

The mean groundwater potential heads of the shallow and deep aquifer are simulated by the model. The groundwater dynamics is, however, underestimated for some of the deeper observation wells.

The model does not meet the calibration targets for the entire simulation period or for all calibration references.

Given the quantity of input data the calibration is satisfactory. The model calibration accuracy must be evaluated against the uncertainty of input data and the complexity of the Caloosahatchee basin hydrology. To obtain a closer agreement between observations and simulation further data must be provided.

5.1.2 Possible model improvements

In the development of the ISGM model the available field data have been utilized. The developed model must be comprehensive to describe the dynamics and interactions of the basin hydrology. A number on general assumptions and approximations are necessary, in any model application, due to conceptualization, limitation in available input data and distribution of model parameter.

When focusing on input data the most critical shortcomings are found in:

- River flow and water levels:

Data for cross section, flood plains and hydraulic structures are sufficient to simulate the overall runoff and water levels in the basin. As the input data to a large extent is based on approximate data an accurate description of canal hydraulics and flood extent is not possible. On local scale more data must be provided to obtain e.g. a reliable flood mapping and detailed simulation of water levels and flows.

- The groundwater model

The groundwater model includes two numerical layers and four geological layers based on geological interpretation of previous model work. If lithological data are collected and reinterpreted the geological model may be extended and refined. Although hydraulic parameters are not available for each layer a further sub-division is likely improve the simulated heads.

The groundwater drainage component is important to the model results. It is desirable to provide a consistent method of transferring field data (e.g. density and depth of tertiary canal system to drainage depths and drainage time constants).

- Irrigation description

The irrigation description based on simulated water demands is seen as highly suitable for the Caloosahatchee basin. Uncertainties are related to which areas should be considered irrigated, what are their primary and secondary sources and if the distribution method applied representative for all crops (e.g. sugar cane). Comparing different methods for calculating irrigation water demands and field measurements to the model results is important in determining if the adopted description should be refined.

Furthermore, crop specific evapotranspiration rates are desirable to reduce uncertainties in total evapotranspiration losses and generated irrigation demands.

5.1.3 Model applicability

The Caloosahatchee ISGM is developed to assist in water management of the Caloosahatchee basin. The model is found to simulate the water use and the water budget with sufficient accuracy to be used for impact assessments focusing on future development incorporating management initiatives to improve the water resources situation in the basin.

The ISGM model incorporates both surface water and groundwater and allows impact assessment of a wide range of management options e.g. storage of surface water (reservoirs).

Considering the calibration accuracy it is advisable to minimize the uncertainty by interpreting the relative changes between a bas scenario and various management scenarios.

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